OPERATING INSTRUCTIONS

TYPE 1606-A

R-F BRIDGE

1606-A

GENERAL RADIO COMPANY

SPECIFICATIONS

Frequency Range	400 kc to 60 Mc.
Reactance Range	±5000 ohms at 1 Mc. This range varies inversely with frequency; at other frequencies the dial reading must be divided by frequency in Mc.
Resistance Range	0 to 1000 ohms.
Accuracy	
Reactance at frequencies up to 50 Mc	$\pm(2\% + 1\Omega + 0.0008\,Rf)$, where R - measured resistance in ohms f - frequency in Mc.
Resistance at frequencies up to 50 Mc.	$\pm\left[1\% + 0.0024f^2\left(1 + \frac{R}{1000}\right)\% \pm \frac{10^{-4}X}{f}\Omega + 0.1\Omega\right]$, where R - measured resistance in ohms X - measured reactance in ohms f - frequency in Mc. Above is subject to correction for residual parameters (see Figures 7 and 8). Accuracy is reduced beyond nominal limits of frequency (400 kc and 60 Mc). The f^2 term is important only at frequencies above 10 Mc. The 1/f term is important at very low frequencies when the resistance of a high-reactance, low-loss capacitor is measured.
Accessories Supplied	Two leads, 7 and 22 inches long, for connecting unknown impedance to bridge terminals; two Type 874-R22 Coaxial Cables for connecting generator and detector to bridge; one Type 874-PB58 Panel Connector; one 1/2-in. spacer; and one 3/4-in. 6-32 screw.
Other Accessories Required	R-f generator and detector. The Type 1330-A Bridge Oscillator and Type 1211-B Unit Oscillator are satisfactory generators, as are the Types 1001-A and 805-C Standard-Signal Generators. Above 50 Mc, a Type 1215-B Unit Oscillator or a Type 1021-AV Standard-Signal Generator is recommended. A well-shielded communications receiver covering the desired frequency range makes a satisfactory detector. It is recommended that the receiver be fitted with the Type 874-PB58 Panel Connector or any other coaxial connector to avoid leakage at the input connection.
Mounting	Welded aluminum cabinet supplied. A luggage-type carrying case is available separately and is recommended if the bridge is to be used as a portable field instrument.
Dimensions	Width 12-1/2, height 9-1/2, depth 10-1/4 inches (320 by 250 by 260 mm), over-all.
Net Weight	23 lb (10.5 kg) without carrying case, 29 lb (13.2 kg) with carrying case.

U.S. Patent No. 2,548,457; 2,376,394.

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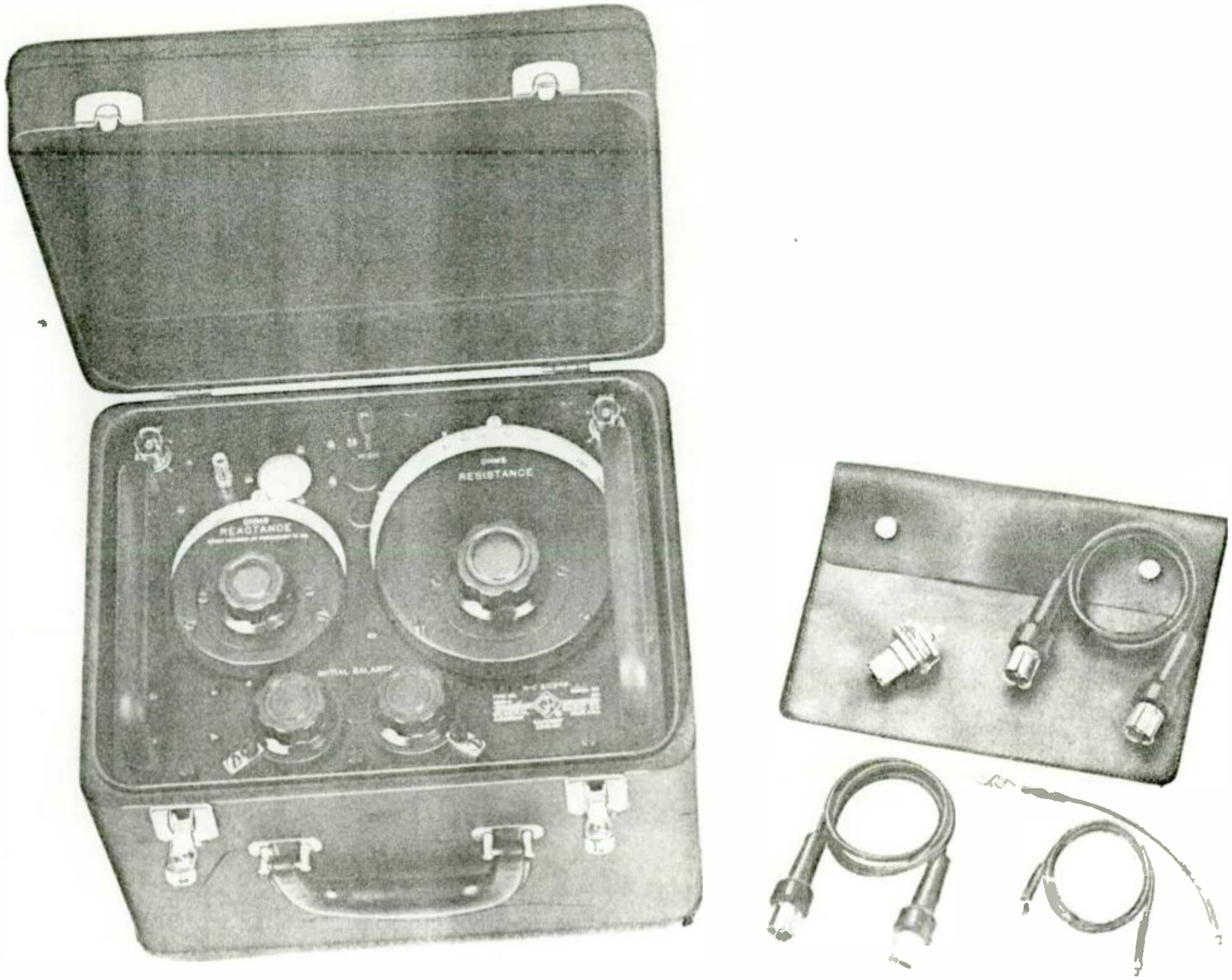


Figure 1. Type 1606-A R-F Bridge. (Luggage-type carrying case available as accessory.)

TYPE 1606-A R-F BRIDGE

Section 1

INTRODUCTION

1.1 PURPOSE. The Type 1606-A R-F Bridge (Figure 1) is a null instrument especially useful for accurate measurement of antennas, r-f components, and other circuits having relatively low impedances. The frequency range of the bridge is from 400 kc to 60 Mc. Measurements can be made, with reduced accuracy, at frequencies somewhat above and below the nominal limits. The low-frequency limit is determined mainly by sensitivity considerations, and satisfactory measurements can usually be made at frequencies as low as 100 kc.

1.2 DESCRIPTION.

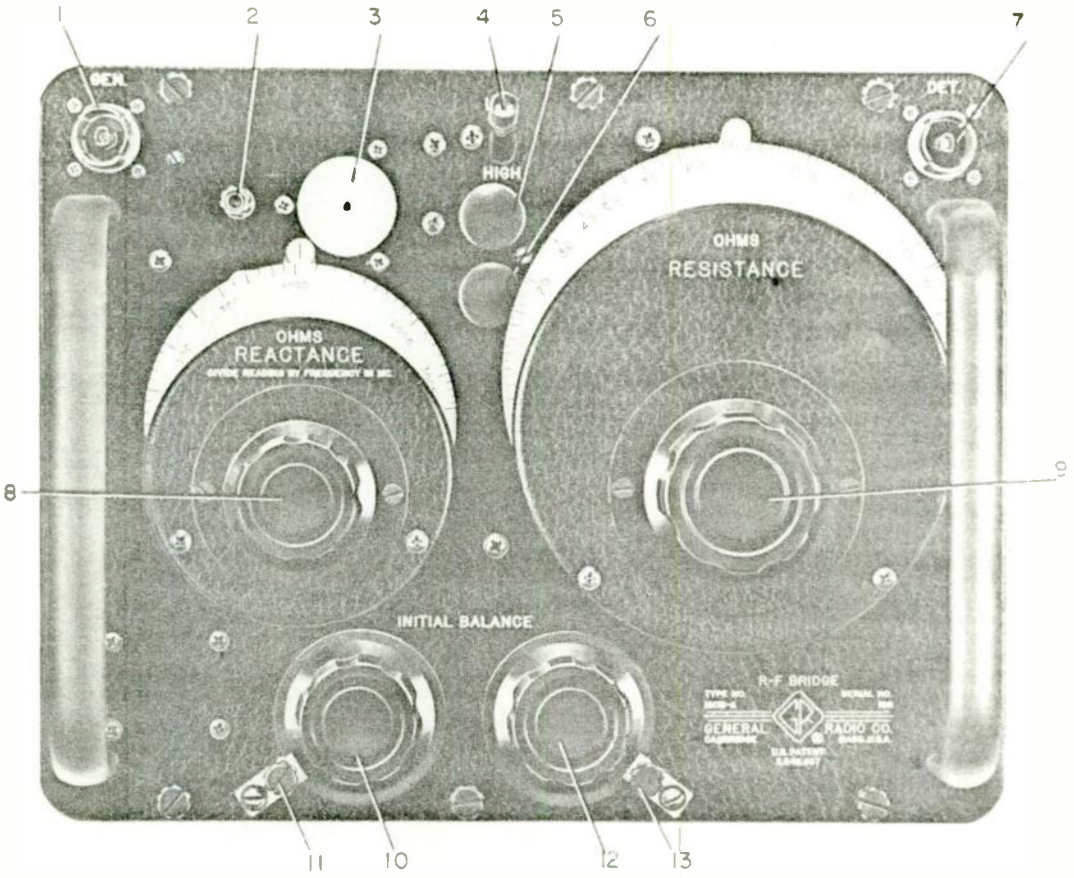
1.2.1 GENERAL. The bridge is mounted in an aluminum cabinet. Since capacitance between the bridge components and the inside walls of the cabinet comprises one arm of the bridge, the instrument cannot be used outside of the cabinet. For rough usage in field applications, a separate luggage-type carrying case is available as an accessory. The bridge can be operated either inside or outside of the luggage case.

1.2.2 CONTROLS. The following controls are on the panel of the instrument (see Figure 2):

Control	Description	Function
REACTANCE	Vernier knob and four-inch dial	Indicates reactance.
RESISTANCE	Vernier knob and six-inch dial	Indicates resistance.
INITIAL BALANCE	Two rotary controls, with locking mechanisms	Used to obtain initial reactance and resistance balance
LOW, HIGH	Two-position toggle switch	Used to establish initial balance setting of the REACTANCE dial in the vicinity of 0 or 5000 ohms.
Capacitors (2)	Adjustments covered by snap buttons	Resistance calibration adjustment.

1.2.3 CONNECTIONS. The following connections are on the panel of the instrument (see Figure 2):

Connection	Description	Function
GEN.	Coaxial connector	Connects generator to bridge.
DET.	Coaxial connector	Connects detector to bridge.
	Binding post	Ground connection to unknown impedance.
	Tapped (6-32) terminal in circular window	Connection for unknown impedance.



1. Generator connection
2. Ground binding post
3. Connection for unknown
4. Initial-balance range switch
5. Resistance calibration adjustment (HIGH range)
6. Resistance calibration adjustment (LOW range)
7. Detector connection
8. Reactance control
9. Resistance control
10. Reactance initial-balance control
11. Locking mechanism
12. Resistance initial-balance control
13. Locking mechanism

Figure 2. Panel Controls and Connections.

1.2.4 ACCESSORIES SUPPLIED. The following accessories are supplied with the Type 1606-A R-F Bridge:

a. Two clip leads for connecting the unknown impedance to the bridge, one about seven inches long, the other about 27 inches. Each lead has a threaded stud on one end and a clip on the other. Leads are stored in the accessory pouch when not in use.

b. A 3/4-in., 6-32 screw and a spacer 1/4 inch in diameter and 1/2 inch long. These are mounted on the unknown terminal to elevate the connection to the same level as the binding-post mounting hole, so that, if desired, a component can be connected directly between the ground binding post and the unknown terminal without the use of leads.

c. Two Type 874-R22 Double-Shielded, three-foot Patch Cords for connections to generator and detector. These cords are fitted with Type 874 Coaxial Connectors.

d. One Type 874-PB58 Coaxial Panel Connector for mounting on the detector, if necessary, since for best results the detector should be fitted with a coaxial r-f input connector to complete the continuity of shielding. At higher frequencies the reactance of a binding post or of an inch of wire may cause noticeable error.

Section 2

PRINCIPLES OF OPERATION

2.1 GENERAL CIRCUIT DESCRIPTION AND BALANCE CONDITIONS. The basic circuit of the Type 1606-A R-F Bridge is shown in Figure 3. An initial balance is made with the unknown terminals short-circuited. The short-circuit is then removed, and the bridge rebalanced with the unknown impedance connected to the terminals.

When the terminals are short-circuited, the balance conditions are:

$$R_p = R_b \cdot \frac{C_{a1}}{C_n}$$

and

$$\frac{1}{j\omega C_{p1}} = \frac{R_b}{R_a} \cdot \frac{1}{j\omega C_n}$$

where C_{a1} and C_{p1} are the capacitances of the variable capacitors in the short-circuit balance position. When the short-circuit is replaced by the unknown impedance $Z_x = R_x + jX_x$, the new balance equations are:

$$R_p + R_x = R_b \frac{C_{a2}}{C_n}$$

and

$$jX_x + \frac{1}{j\omega C_{p2}} = \frac{R_b}{R_a} \cdot \frac{1}{j\omega C_n}$$

where C_{a2} and C_{p2} are the capacitances of the variable capacitors with the unknown impedance in the circuit.

The unknown resistance R_x and the reactance X_x are therefore related to the bridge constants by the expressions:

$$R_x = \frac{R_b}{C_n} \cdot (C_{a2} - C_{a1})$$

and

$$X_x = \frac{1}{\omega}\left(\frac{1}{C_{p2}} - \frac{1}{C_{p1}}\right)$$

The resistance R_x is proportional to the change in capacitance C_a, and the reactance X_x depends upon a change in capacitance C_p. The constant that relates resistance R_x to change in capacitance C_a is determined by the fixed resistance R_b and fixed capacitance C_n. The reactance X_x is actually measured by the reactance substitution method, and is equal and opposite in sign to the change in reactance of the capacitor C_p.

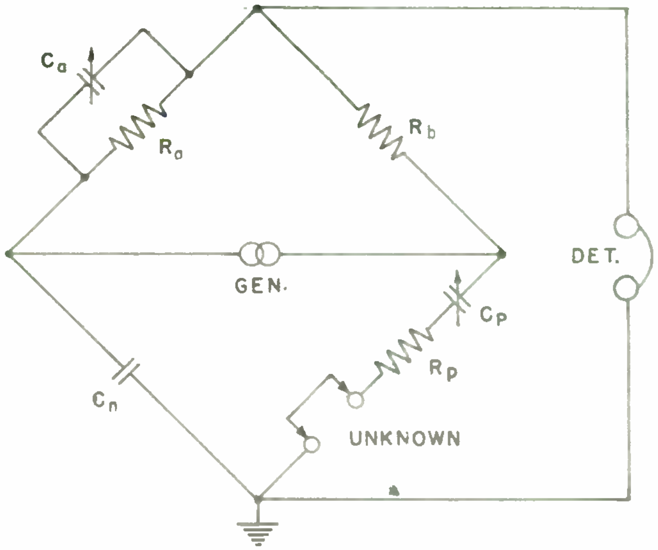


Figure 3. Basic Circuit of the Type 1606-A R-F Bridge.

2.2 DETAILED CIRCUIT DESCRIPTION.

2.2.1 GENERAL. Simple relationships between the unknown resistance, reactance, and increments of capacitance are obtained by the series-substitution method of measurement. For simplicity of operation, auxiliary controls not shown in the basic diagram are added. Their functions are most easily described by separate discussions of the resistance and reactance balances.

2.2.2 RESISTANCE MEASUREMENT. The RESISTANCE dial, which controls variable capacitor C1 (see schematic diagram, Figure 10), can be calibrated in resistive ohms, with any capacitive setting as zero. For the maximum resistance range, this setting is chosen at minimum capacitance. A small variable trimmer capacitor, C2, is then connected in parallel with C1, so that the initial resistance balance, with the unknown terminals short-circuited, can be made at zero dial setting, irrespective of slight changes in the bridge parameters with time or frequency.

2.2.3 REACTANCE MEASUREMENT. The REACTANCE dial, which controls variable capacitor C3, can be calibrated in reactive ohms at any one frequency, again with any capacitance setting as zero.

For the maximum reactance range and the best scale distribution, this setting is chosen at maximum capacitance. A variable trimmer capacitor, C4, is then connected in series with C3, so that the initial reactance balance, with the unknown terminals short-circuited, can be made at zero dial setting or at other points on the dial, irrespective of changes in the bridge parameters with time or frequency.

Another auxiliary control permits the measurement of both capacitive and inductive reactances equally well. With the zero position on the REACTANCE dial established at maximum capacitance, the dial scale reads inductive reactance directly; for measurements of capacitive reactance, the initial balance must be made at an upscale reading so that the negative change in dial reading will remain on scale. Since the range of adjustment of the INITIAL BALANCE control does not permit initial balances to be established over the entire scale, a two-position (LOW, HIGH) switch is provided to shift the initial-balance adjustment range to either the top or bottom end of the dial by changing the value of the ratio-arm resistor (R1-R2). With this switch in the LOW position, initial balance can be obtained with the REACTANCE dial set from zero to about 1000, for the measurement of inductive reactances and relatively small capacitive reactances. With the switch at HIGH, an initial balance can be obtained in the vicinity of the maximum setting of the REACTANCE dial, for the measurement of large capacitive reactances. The unknown reactance equals the difference in the REACTANCE dial reading between the two balances divided by the frequency in megacycles, no matter where the dial is set for the initial balance.

2.2.4 CIRCUIT DIAGRAM. Figure 10 is a complete schematic diagram, showing the ratio-arm switch S1 and the two trimmer capacitors C2 and C4. In the instrument, the fixed capacitance C7 is composed chiefly of the capacitance to ground of the shielding system. The small adjusting capacitors, C5 and C6, are used to equalize the capacitance from point A to ground in the two positions of S1.

Section 3

INSTALLATION

3.1 GENERAL. The complete measurement setup usually consists of the Type 1606-A R-F Bridge, a well-shielded radio-frequency oscillator, and a well-shielded radio receiver, which serves as a detector.

3.2 OSCILLATOR. The r-f oscillator must be capable of covering the frequency band of 400 kc to 60 Mc (or any desired portion thereof) with a maximum output voltage of between 0.1 and 10 volts. (For measurements on broadcast antennas, the maximum possible oscillator voltage should be used to override interference.)[1] The oscillator should have a coaxial output connector. (The Type 1211-B Unit Oscillator, with a range of 0.5 to 50 Mc, is especially recommended.) Also, the following instruments may be used as signal generators for the frequencies indicated:

Instrument	Range
Type 1210-B Unit R-C Oscillator	20 cps - 0.5 Mc
Type 1215-B Unit Oscillator	50 - 250 Mc
Type 1330-A Bridge Oscillator	5 kc - 50 Mc
Type 805-C Standard-Signal Generator	16 kc - 50 Mc
Type 1001-A Standard-Signal Generator	5 kc - 50 Mc

3.3 DETECTOR. The receiver should have a sensitivity control, a beat frequency oscillator, a switch to cut out the AVC circuit, and coverage of the frequency band of 400 kc to 60 Mc, or any desired portion thereof. Conventional communication-type receivers are usually satisfactory. For best results, the receiver should be equipped with a coaxial input connector. The Type 874-PB58 Coaxial Panel Connector is supplied as an accessory for installation on receivers not so equipped.

3.4 GROUNDING. When the instrument is used for antenna impedance measurements, it should be grounded at a single point, through a connection of as low reactance as possible. When the instrument is used to measure impedance of components, grounding is usually not required. To facilitate

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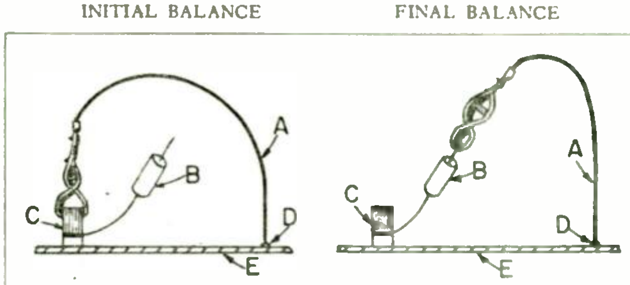
[1] See Appendix 1

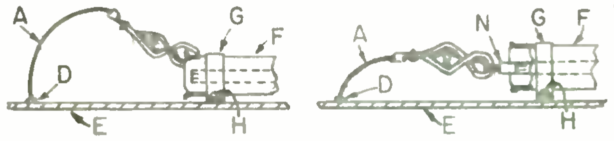
making the ground connection, a ground clamp is provided on the instrument case. The ground lead should be a short length of copper strip, about an inch wide. In a maintenance shop setup, a satisfactory ground can be made by copper foil covering the top of the bench, even though the bench is physically far removed from ground. If the foil area is large enough, it will usually be found that a connection from it to ground (e.g. through a steam radiator system) will make no appreciable difference in results. The foil area should be at least great enough so that the generator, bridge, and detector can all be placed upon it. Large metal structures, such as relay racks, are also found to be adequate grounds. If the grounding is inadequate, it will usually be found that the instrument panel is at a different potential from the hand of the operator, and that the balance can be changed if the panel is touched.

3.5 STRAY PICKUP. If the bridge panel is at ground potential and the generator and detector panels are not, it is usually an indication of excessive reactance in the connections from the outer conductors of the coaxial leads to the generator and detector panels. Use of the double-shielded, single-conductor coaxial cables supplied, with coaxial connectors on both generator and detector panels, will generally eliminate these differences in potential.

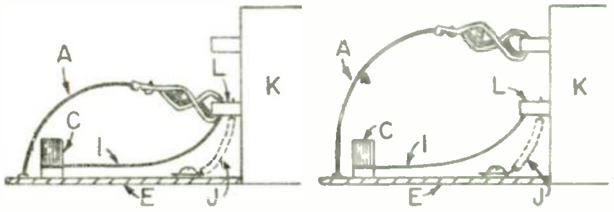
As a check for stray pickup, balance the bridge with the unknown terminals short-circuited and remove the detector cable from the panel jack of the bridge. The detector pickup should be negligible if the generator is adequately shielded. If the outer shell of the cable jack can be touched to the ground shell of the detector connector without significantly increasing the receiver output, no excessive reactance exists. If the detector, when disconnected from the bridge, shows considerable pickup, it is usually an indication of poor shielding in the generator and detector or of energy transfer from the generator to the detector through the power line. The leakage can also be produced by a faulty cable. It is sometimes found, where grounding conditions cannot be carefully controlled, that individual ground connections from the generator, bridge, and detector panels to a common ground point give less pickup and better results than a single common ground to the bridge alone. The use of coaxial cables and connectors at both generator and detector is par-



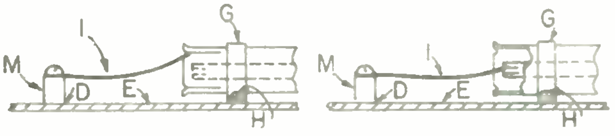
a. Method can be used over entire range. Above 20 Mc use 2-in. or shorter bus wire or terminals alone for greater accuracy. If unknown impedance is low, orient unknown parallel to panel to keep clip-lead position identical in both balances.



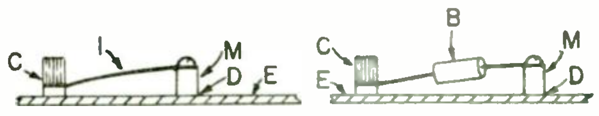
b. Short clip lead used to measure input impedance to coaxial line. Above 20 Mc use short bus wire for greater accuracy.



c. Physically large unknown. For initial balance, connect clip lead to ground terminal or short input terminals to network by copper strap. Above 5Mc use ground strap directly to panel instead of bus wire to binding post.



d. Short No. 20 bus wire used to measure input impedance to coaxial line. For initial balance, short inner and outer coaxial conductors by a strap, or connect bus wire to grounded shell of coaxial line. Most accurate method, especially at higher frequencies



e. Component connected directly to bridge terminals. Recommended for accurate measurements on small components, especially above 20 Mc.

Figure 4. Methods of Connection.

Key to Figure 4.

A - Short clip lead
B - Unknown component
C - Ground binding post
D - Unknown terminal
E - Bridge panel
F - Coaxial line
G - Clamp
H - 10-32 screw substituted for panel screw
I - Bus wire
J - Strap (recommended at high frequencies)
K - Network under test
L - Ground terminal
M - Spacer
N - Banana pin or Type 874-61-4 Inner Conductor

ticularly recommended to avoid as much as possible the necessity for such multiple ground connections. In some cases, the effects of stray pick-up are reduced if the generator and detector connections are reversed.

For a further check for stray pickup, repeat the procedure described earlier in this paragraph, with the generator cable in place of the detector cable. For antenna measurements, check for coupling between the antenna and the generator or detector by repeating the above checks with the antenna connected to the unknown terminals and the bridge balanced.

3.6 PRELIMINARY ADJUSTMENTS. The following adjustments must be made to prepare the instrument for use:

a. Connect the generator and detector to the bridge, using the cables and connectors provided.

b. Ground the equipment if necessary. (Refer to paragraph 3.4.)

c. Set the generator and detector to the proper frequencies. The input signal should be cw (unmodulated) to prevent possible difficulties arising from side bands.

d. Connect leads according to paragraph 3.7.

3.7 LEAD APPLICATIONS. The following types of leads should be used for the applications indicated (see Figure 4):

a. Long clip lead (supplied) - Use only when short lead cannot be used, and then only at frequencies below 5 Mc.

b. Short clip lead (supplied) - Useful over the frequency range of the bridge. For greatest accuracy, especially at frequencies above 20 Mc, use a two-inch or shorter bus wire or the terminals themselves.

c. Bus wire leads - A two-inch or shorter lead is recommended, particularly at frequencies above 20 Mc. If longer leads are used at lower frequencies, their capacitances to ground must be measured or estimated (refer to paragraph 4.4).

d. Bridge terminals - Most accurate measurements result when the unknown impedance can be mounted directly across the bridge terminals.

Use of the terminals alone and terminals with a short bus wire lead also have the advantage of confining the important electrostatic fields to a relatively small area and thus minimizing hand capacitance effects, which may be noticeable when small capacitors are measured.

Section 4

OPERATING PROCEDURE

4.1 INITIAL BALANCE.

4.1.1 PROCEDURE.

a. Set controls for initial balance as follows:

(1) If unit to be measured has an inductive reactance, set switch to LOW, and REACTANCE and RESISTANCE dials to zero.

(2) If circuit is known to have a capacitive reactance, set switch to HIGH, REACTANCE dial to 5000, and RESISTANCE dial to zero.

(3) If the sign of the reactance is unknown, set switch to HIGH, REACTANCE dial to about 3400, and RESISTANCE dial to zero. The mid-dial setting makes it possible to obtain a balance or at least an indication of the sign of the reactive balance with either inductive or capacitive unknowns.

b. Balance the bridge to a null by varying the INITIAL BALANCE controls.

4.1.2 LIMITS. At lower frequencies, with the switch at LOW, initial balance can be obtained at REACTANCE settings from zero to about 1200; with the switch at HIGH, from about 3100 to 5000. As the frequency is raised, these reactance limits tend to move up the dial because of the inductive reactance of the connecting lead. Depending upon the length of the connecting lead, a frequency will be found above which initial balance cannot be obtained with the REACTANCE dial at zero and the switch at LOW. A high frequency will be found at which the initial balance can no longer be obtained with the REACTANCE dial at 5000 and the switch at HIGH. The shift in balance causes no corresponding error in measurement since, in the series-substitution process, the constant inductive reactance of the connecting lead cancels out. It does, however, reduce the reactance range of the bridge, since the full coverage of the REACTANCE dial cannot be obtained. The effect can be corrected, when necessary, by the insertion of a small fixed capacitor (about 200 μμf) in series with the connecting lead to neutralize the inductive reactance.

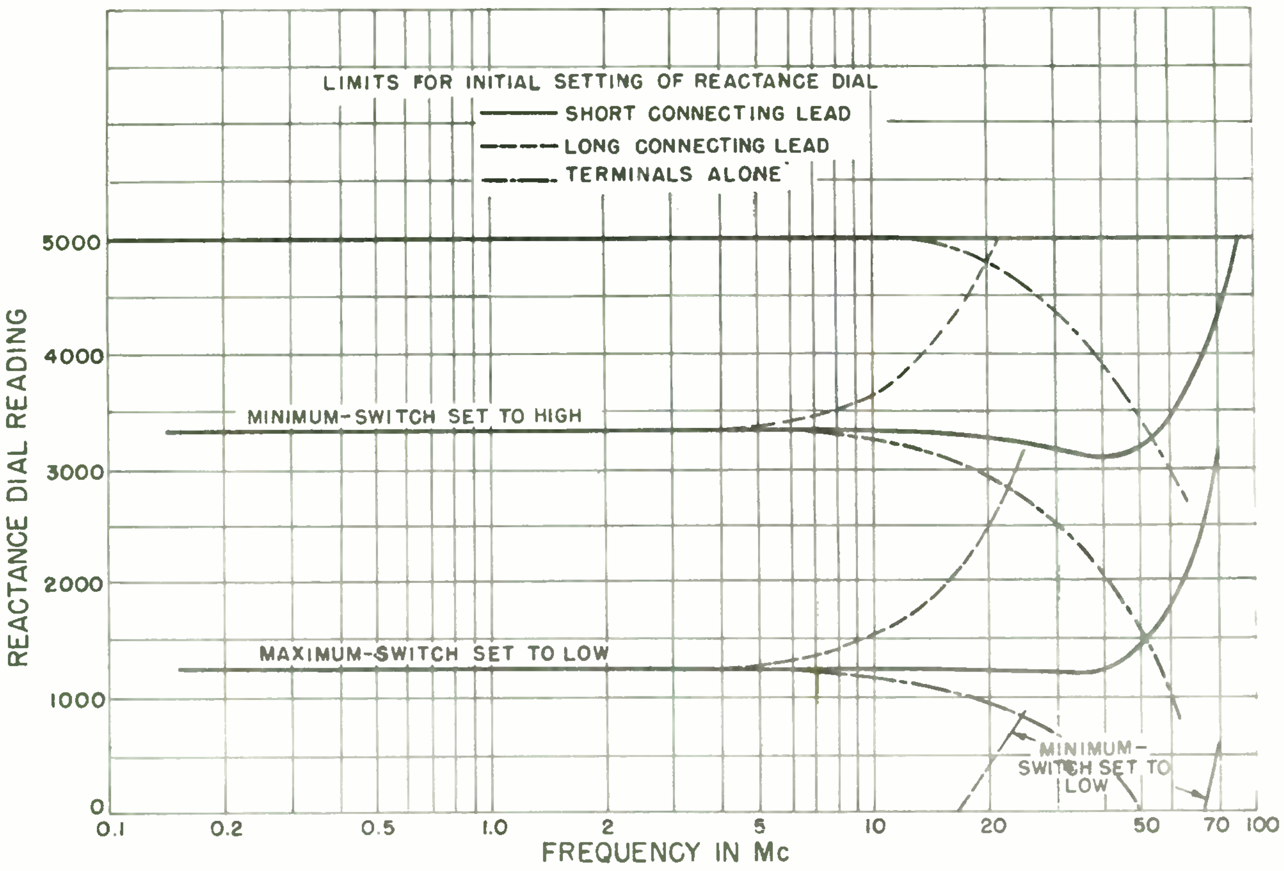


Figure 5. Range of Initial Reactance Dial Setting as a Function of Frequency.

Typical curves of the shifts in initial balance are shown in Figure 5. With the short clip lead, as shown, the shift is relatively small over the entire frequency range of the instrument, and it is usually not necessary to use a series capacitor at any frequency. With the long lead, the shift is appreciable, and at frequencies above 15 or 20 Mc a series capacitor may be necessary. However, the use of the long lead at these frequencies is not recommended as the errors are liable to be fairly large.

When a short bus wire is used for the connecting lead, or when the unknown is connected directly across the bridge terminals, the initial-balance range shifts with frequency in the opposite direction from the shift when a clip lead is used (see Figure 5). This reverse shift is caused by compensating reactances, included in the bridge to minimize the initial-balance shift when clip leads are used. At the highest frequencies, the bridge cannot be balanced in the vicinity of 5000 or at zero, but it can be balanced over most of the intermediate range.

4.1.3 NULL DETERMINATION. To balance to a null, adjust the bridge controls until the signal indicated by the detector disappears. Either an aural or a visual indication of signal amplitude may be used. If an aural indication is used, the receiver beat-frequency oscillator should be switched on and tuned to produce an audible beat in the headset. The r-f gain control on the receiver should be set at a level at which the receiver is not saturated. Then, with the receiver AVC off, a rough null should be found. The r-f gain should then be increased, and a more accurate null found. This process should be repeated until the null is located with adequate accuracy. If a visual indication is desired, the S meter on the receiver can be used. (For this purpose, the AVC should be on.) The null can then be determined from a minimum meter reading. The r-f gain control should be set at the maximum level required to obtain a balance with the desired precision of measurement. Usually, the most satisfactory method is a combination of the visual and aural methods, in which the rough balance is made with the headset, with the AVC on. The precise balance should be made with the generator signal unmodulated. The AVC tends to broaden the null, and sometimes makes locating the null more difficult. Therefore, operation of the AVC should be left to the discretion of the operator. If the receiv-

er does not have an adequate r-f sensitivity control, reducing the generator output or detuning the receiver may produce the same general results. For precise balance, the generator output should be set at maximum, so that the ratio of useful output to leakage is as great as possible.

4.2 MEASUREMENT OF UNKNOWN IMPEDANCE WITHIN DIRECT-READING RANGES OF BRIDGE.

a. Connect the ground terminal of the unknown impedance to the bridge panel. Use as short a lead as possible. See Figure 4 for suggested methods of connecting various types of unknowns. (For an inherently grounded impedance, such as a low-frequency antenna, this ground connection can be omitted, since the bridge is already grounded through a low-reactance connection. Refer to paragraph 3.4.) The unknown should be located so that it can be reached with one of the two connecting leads supplied, or with a short bus wire (about No. 20), or connected by its own leads across the unknown terminals.

b. Clip the connecting lead to the ground terminal of the unknown impedance (or short-circuit the terminals of the unknown with a low-inductance strap) and establish an initial balance (refer to paragraph 4.1). If the component is to be connected by means of its own leads between the ground binding post and the unknown terminal, substitute a short bus wire or strapping for the component.

c. Remove the connecting lead from the grounded terminal of the unknown impedance, connect to the ungrounded terminal (or remove the short-circuit from the unknown), and rebalance with the RESISTANCE and REACTANCE controls. The location of the connecting lead should be altered as little as possible when the clip is shifted from the grounded to the ungrounded terminal, in order to minimize the changes in the lead inductance. If the unknown is to be connected by its own leads, substitute the unknown for the bus wire or strapping used for initial balance (refer to step b).

d. Read the unknown resistance directly on the RESISTANCE dial. The unknown reactance equals the change in reading of the REACTANCE dial, for any initial setting, divided by the frequency in megacycles. If the unknown reactance is inductive, the maximum dial-reading accuracy and range is obtained when the initial setting is made at zero.[1] Under these conditions, the change in reading of the REACTANCE dial equals the final dial reading. If the unknown reactance is capacitive and large in magnitude, the initial setting should be made at 5000 ohms.[2] The change in reading of the REACTANCE dial then equals 5000 ohms minus the final dial reading.

e. Due to the compression of the REACTANCE scale at the high end, the precision of measurement with the REACTANCE dial initially set at 5000 may not be the highest attainable when a capacitive reactance that produces a dial reading difference of less than 5000 ohms is measured. In such instances, accuracy can be improved by a second measurement of the circuit, with the initial REACTANCE setting slightly higher than the difference in readings obtained in the first measurement. If the desired initial reactance setting lies in the range (see Figure 5) over which initial balance is possible with the switch at LOW, set the switch at LOW for the initial balance. If the desired initial REACTANCE setting is in the range (see Figure 5) in which no initial balance is possible, set the REACTANCE dial near the lowest point at which an initial balance is possible with the switch at HIGH.

f. The following is another method of achieving the same result for capacitive reactances producing less than 1000 ohms differences in the REACTANCE readings:

(1) Set the RESISTANCE dial to the resistance previously measured (as in d, above) and the REACTANCE dial to zero.

(2) Clip the connecting lead to the ungrounded terminal of the unknown impedance.

(3) Obtain an initial balance with the switch at LOW.

(4) Clip the connecting lead to the grounded terminal and rebalance with the RESISTANCE and REACTANCE dials. The REACTANCE dial then reads upscale for capacitive reactance, and the precision of reading is the same as for inductive reactance. This method has the disadvantage of requiring two sets of balances, one to determine the resistive component and the other to determine the reactive component.

g. If it is not known whether the reactive component of the impedance to be measured is inductive or capacitive, the following procedure is helpful: For initial balance, set the switch to HIGH and the REACTANCE dial to the lowest setting at which initial balance is possible (normally not above 3400 ohms). This setting permits a change in scale reading of 1600 ohms inductive or 3400 ohms capacitive.

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[1] When a short bus wire lead or no lead is used, it may not be possible to obtain an initial balance at zero at frequencies above 50 Mc. If initial balance is not obtainable with the switch at LOW, switch to HIGH and obtain an initial balance at the lowest possible REACTANCE dial setting. The measured inductive reactance is then the difference between final and initial REACTANCE dial readings divided by the frequency in Mc.

[2] When a short bus wire lead or no lead is used, it may not be possible to obtain an initial balance at 5000 at frequencies above 10 Mc. Under these conditions, set the REACTANCE dial at the highest setting at which an initial balance is obtainable.

If the receiver sensitivity is turned down, this available reactance range is sufficient to indicate the approximate magnitude and sign of the unknown reactance, or, if the reactance is greater than the above limits, the direction in which the dial must be turned for a reactance balance is indicated, and a new initial balance can be established accordingly.

4.3 MEASUREMENT OF UNKNOWN IMPEDANCE OUTSIDE DIRECT-READING RANGES OF BRIDGE. If the resistive or reactive component of the unknown impedance falls outside of the direct-reading range of the bridge, indirect measurements can be made through the use of an auxiliary parallel capacitor. When a pure reactance, jX_a, is connected in parallel with the unknown impedance, $Z_x = R_x + jX_x$, and as X_a approaches zero, the effective input impedance, $Z_m = R_m + jX_m$, becomes

$$R_m \cong R_x \frac{X_a{}^2}{R_x{}^2 + X_x{}^2}$$

$$X_m \cong X_a$$

"Shunting down" a high impedance with a parallel capacitor will accordingly bring either or both the resistive and reactive components within the measurement range of the bridge. To measure a high impedance by this method, proceed as follows:

a. Connect one lead of the auxiliary capacitor to the ground terminal of the unknown impedance, and place the other lead near the ungrounded terminal of the unknown.

b. Establish an initial balance and measure the capacitive reactance (X_a) of the auxiliary capacitor as described in paragraph 4.2.

c. Connect the ungrounded lead of the auxiliary capacitor to the ungrounded terminal of the unknown, keeping the capacitor-lead length as near as possible to that used in the measurement with the actual unknown connected.

d. Measure the effective impedance appearing across the bridge terminals, $Z_m = R_m + jX_m$. Then calculate the unknown impedance from the relations

$$R_x = \frac{R_m}{A} \qquad (1)$$

$$X_x = \frac{X_m - \dfrac{R_m{}^2}{X_a} - \dfrac{X_m{}^2}{X_a}}{A} \qquad (2)$$

where

$$A = \left(1 - \frac{X_m}{X_a}\right)^2 + \left(\frac{R_m}{X_a}\right)^2$$

Since the auxiliary reactance (X_a) is capacitive, the number to be inserted for X_a on equations (1) and (2) will be negative. The sign of the effective reactance (X_m) will be positive or negative depending on whether the measured value is inductive or capacitive.

The value of the auxiliary capacitor to be used is easily determined by experiment. It should be kept reasonably small, so that impedances to be measured are not reduced so far that precision of dial reading is lost. A value between 35 and 200 μμf is usually satisfactory. The resistance (R_a) of the auxiliary capacitor is generally negligible, but can be corrected for as follows: Subtract from the effective resistance (R_m) of the parallel combination (capacitor and unknown) a resistance

$$\Delta R = R_a \frac{X_m{}^2 - R_m{}^2}{X_a{}^2}$$

The corrected value of R_m can then be substituted in equations (1) and (2). For example, if, at a frequency of 2 Mc, an auxiliary mica capacitor of approximately 100 μμf is used with the short clip lead, its reactance should be about 800 ohms, corresponding to a difference of 1600 in initial and final REACTANCE dial readings. Since an initial balance cannot be obtained with the REACTANCE dial set at 1600, the dial should initially be set at the lowest practical setting above 1600 at which initial balance is possible. Say this turns out to be 3400, with the switch set at HIGH. The short clip lead is connected to ground and the initial balance is made. Then the clip is connected to the auxiliary capacitor and the bridge is rebalanced with the RESISTANCE and REACTANCE dials. The final readings are 0.5 and 1840, respectively. Therefore:

$$R_a = 0.5 \text{ ohm}$$

$$X_a = \frac{(1840 - 3400)}{2} = -780 \text{ ohms}$$

The circuit to be measured is then connected to the clip lead with the auxiliary capacitor, and to the ground binding post, and the bridge is rebalanced. The final RESISTANCE reading is 115 ohms and the final REACTANCE reading is 2020. Therefore:

$$R_m = 115 \text{ ohms}$$

and

$$X_m = \frac{(2020 - 3400)}{2} = -690 \text{ ohms}$$

(At the higher frequencies, R_m and R_a must be corrected for the effects of inductance in the RESISTANCE capacitor. Refer to paragraph 4.5.)

The correction for the resistance of the auxiliary capacitor is

$$\Delta R = 0.5\left(\frac{690^2 - 0.5^2}{780^2}\right) = 0.4 \text{ ohm}$$

The corrected effective resistance, R_m', is then

$$R_m' = 115 - 0.4 = 114.6 \text{ ohms}$$

The unknown resistance and reactance are calculated from equations (1) and (2) as follows:

$$R_m' = 114.6 \text{ ohms}$$

$$X_m = -690 \text{ ohms}$$

$$X_a = -780 \text{ ohms}$$

$$A = \left(1 - \frac{-690}{-780}\right)^2 + \left(\frac{114.6}{-780}\right)^2 = 0.0351$$

$$R_x = \frac{114.6}{0.0351} = 3270 \text{ ohms}$$

$$X_x = \frac{-690 - \frac{114.6^2}{-780} - \frac{(-690)^2}{-780}}{0.0351} = -1820 \text{ ohms}$$

For this unknown, somewhat greater accuracy would have been obtained if a 35-μμf auxiliary capacitor had been used.

4.4 LEAD CORRECTIONS. In common with other types of impedance-measuring equipment, the bridge can measure impedance only at its own terminals. The residual impedances of the connecting leads often cause this impedance to differ from the impedance appearing at the terminals of the device under test. Under some circumstances, the difference can be ignored and the measured impedance taken as the impedance of the device under test, including the leads. In most instances, however, the device will not be used with the same leads used to connect it to the measuring equipment, and it is necessary to compensate for the effect of the leads to obtain the desired impedance. An exact correction requires an analysis as a transmission line, and the procedure is laborious and cumbersome. Approximate corrections will normally yield satisfactory accuracy.

In paragraph 3.7 it is noted that the length and location of connecting leads to the unknown impedance should be altered as little as possible when the clip is shifted for initial and final balances. This precaution insures that the inductive reactance of the leads is very nearly equal under the two conditions, and therefore that it cancels out in the series-substitution process.

It will be remembered that a short bus wire connection is used for initial balance where the unknown is to be connected directly between the bridge terminals. (See Figure 4.) The inductive reactance of this bus wire connection does effect the measurement, since it is removed when the unknown is measured. The reactance of the bus wire should be added (+ reactance) to the measured reactance of the unknown. For No. 20 bus wire, the reactance at 1 Mc is 0.08 ohm, and is directly proportional to frequency. This correction is negligible, except at higher frequencies, and can be reduced to a negligible value at all frequencies by the use of a wide strap rather than a No. 20 bus wire.

The capacitance to ground of a connecting lead will cause errors in measurement that increase as the frequency is raised. Since the capacitance of a connecting lead to ground has the same effect as a capacitance deliberately placed in parallel with the unknown impedance, the correction for its effect can be determined directly from equations (1) and (2), where $Z_m = R_m + jX_m$ is the observed impedance, and X_a the reactance of the lead impedance. If the connecting leads are kept at a reasonable distance from metal objects, say an inch or more at the closest point, their capacitances to ground are approximately as follows:

Terminals and 1/2-in. spacer	2.0 μμf
Terminals, 1/2-in. spacer, and 2-in. #20 bus wire	2.5 μμf
Short connecting lead	3.8 μμf
Long connecting lead	8.3 μμf

The reactances corresponding to these capacitances are plotted in Figure 6. For example, if a circuit is measured at a frequency of 5 Mc with the short connecting lead (X_a = 8500 ohms), and the effective resistance and reactance are 522 ohms and -55.6 ohms, respectively, the true resistance and reactance of the unknown circuit, corrected for the effect of the lead capacitance, are (from equations 1 and 2):

$$A = \left(1 - \frac{-55.6}{-8500}\right)^2 + \left(\frac{522}{-8500}\right)^2 = 0.991$$

$$R_x = \frac{522}{0.991} = 527 \text{ ohms}$$

$$X_x = \frac{-55.6 - \frac{522^2}{-8500} - \frac{(-55.6)^2}{-8500}}{0.991} = -23.4 \text{ ohms}$$

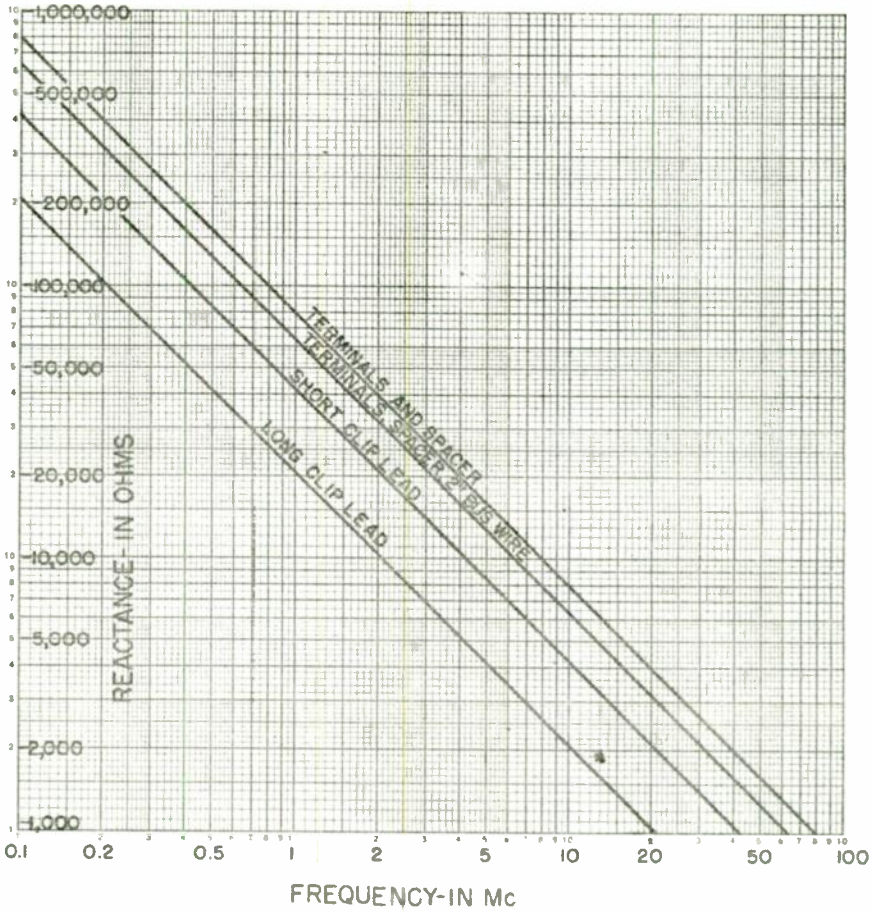


Figure 6. Capacitive Reactance to Ground of Connecting Leads as a Function of Frequency.

When impedance components are measured outside the direct-reading range of the bridge, no lead corrections are necessary. Precautions in keeping the length and position of the connecting lead as nearly the same as possible insures constant inductance, which cancels out in the series-substitution method; the reactance of the connecting-lead capacitance to ground is included in the measured reactance (X_a) of the parallel capacitor.

It should be noted that the foregoing treatment of lead corrections is approximate. For instance, if the inductive reactance of the connecting lead is comparable to the unknown impedance, the voltage to ground will vary along the lead. Also, the effective capacitance will not be the same as it is when the inductive reactance of the lead is small compared with the unknown impedance. In fact, when the unknown impedance is zero, the effective capacitance to ground of a connecting lead will be only one third of the static value. In compensation, it should be noted that the lower the unknown impedance, the less the effect of lead capacitance. Obviously, the shorter the connecting lead, the smaller will be the lead corrections. Use the shortest possible connecting lead, therefore, especially at frequencies above 5 Mc. To aid in estimating the inductive reactance of the leads relative to the unknown impedance, approximate inductance values are as follows:

Short lead	0.14 μh
Long lead	0.71 μh
2-in. #20 bus wire	0.025 μh
1-in. #20 bus wire	0.013 μh

4.5 CORRECTIONS FOR RESIDUAL PARAMETERS. Frequency limits for accurate r-f impedance measurements are nearly always determined by residual parameters in the wiring and in the impedance elements. While these are extremely small in the Type 1606-A R-F Bridge, they are still large enough to affect performance at the highest frequencies and to set the limit of operation at about 60 Mc.

The low-frequency limit is determined by factors that cause the bridge sensitivity to decrease at the lower frequencies and by compression of the REACTANCE dial calibration. For most applications, satisfactory operation is possible at frequencies as low as 100 kc.

The high-frequency limit is determined by the inductance in the resistance capacitor, C1. This

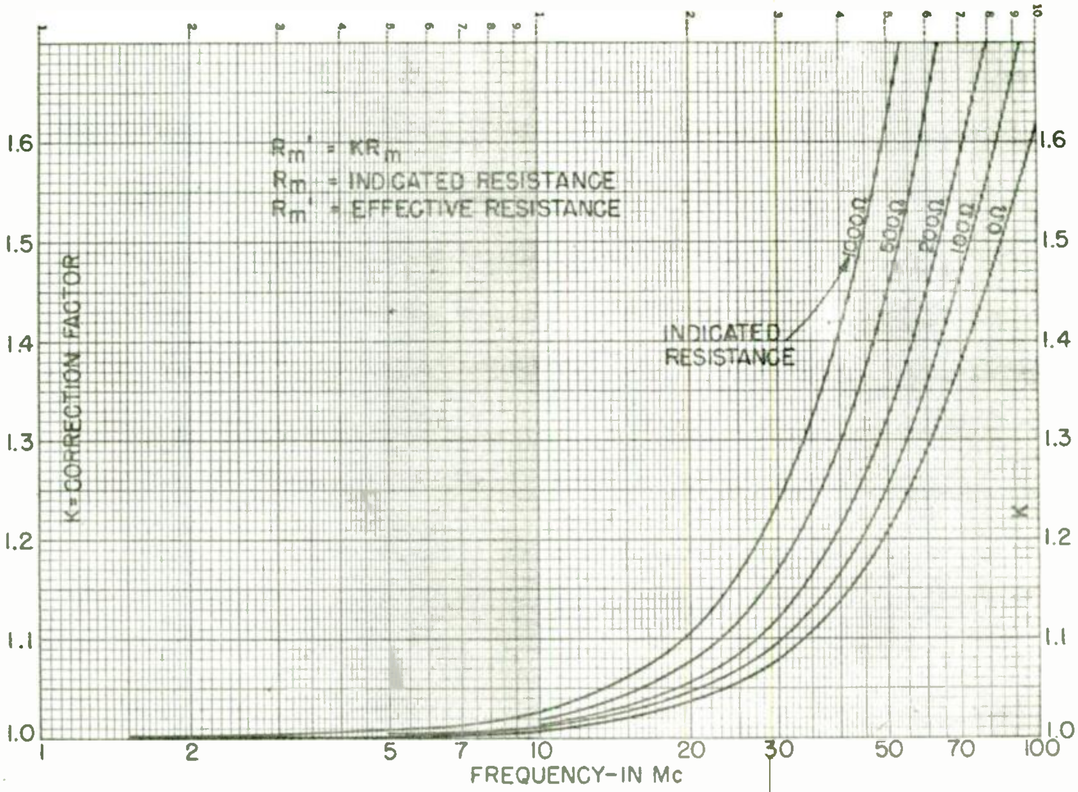


Figure 7. Multiplying Factor for RESISTANCE Dial as a Function of Frequency and ~~Dial Setting (for~~ use with 7-in. connecting lead).

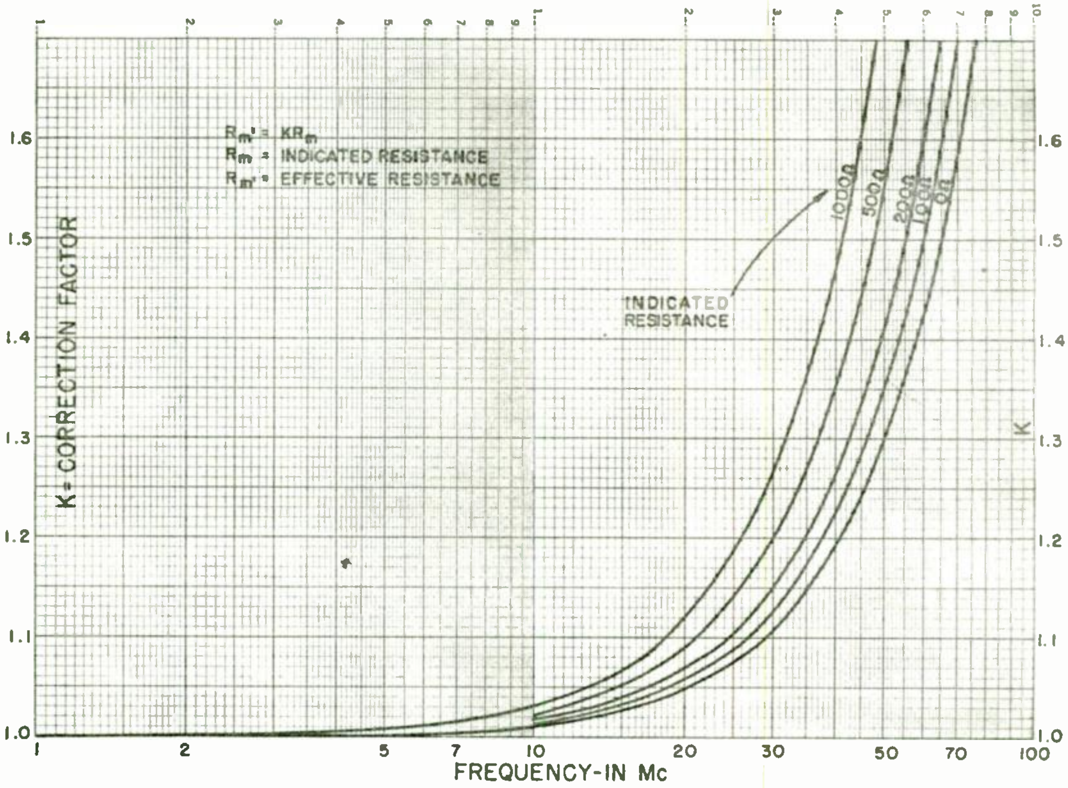


Figure 8. Multiplying Factor for RESISTANCE Dial as a Function of Frequency and Dial Setting (for use with terminals alone or with lead less than 2 inches long).

inductance causes the effective capacitance to increase as the frequency is raised, and therefore causes the dial reading for a given resistance value to decrease. Correction curves are given in Figures 7 and 8. The correction curve in Figure 8 is the actual correction for inductance in the resistance capacitor, and is valid when the unknown is connected directly across the bridge terminals or by means of a connecting lead less than two inches in length. When the short clip lead is used at high frequencies, the absorption of the lead inductance in the initial balance causes an error, which is combined with the resistance capacitor inductance error in Figure 8. (Refer to paragraph 6.2c.) For greatest accuracy at the extreme frequency limits, use a short length of bus wire in place of the 7-in. lead supplied, or connect the unknown directly across the bridge terminals. (Refer to paragraph 4.2.)

Section 5

TYPICAL MEASUREMENT PROCEDURES

5.1 GENERAL. The following procedures are given as a guide to the practical application of the bridge.

5.2 MEASUREMENT OF A 100-μμf CAPACITOR AT 500 KC. The unknown impedance in this example is a small mica capacitor of good power factor.

a. Connect the generator and detector. Assume that the short clip lead has been chosen for this measurement. Screw the lead into the unknown terminal, and check for leakage as outlined in paragraph 3.5.

b. Fasten one end of the capacitor to the binding post, and adjust its location so that the clip of the connecting lead can be transfered from the ungrounded capacitor lead to the grounded capacitor lead with a minimum change in the position of the connecting lead. (See Figure 4a.)

c. Since a capacitive reactance is to be measured, the REACTANCE dial will read downscale; hence it must initially be set at a point higher than the expected change in dial reading. Since here the approximate magnitude of the unknown resistance can be estimated from its nominal capacitance, a satisfactory initial REACTANCE dial setting can be easily determined. The unknown reactance in this case is about 3200 ohms, which corresponds to a 1600-ohm change in dial readings. Therefore, from Figure 5, it can be seen that the switch must be at HIGH and the dial at about the lowest setting at which balance is possible, about 3400 ohms. With the clip lead connected to the ground binding post, and the RESISTANCE dial at zero, set up the initial balance using the INITIAL BALANCE controls. The signal should completely disappear at the balance point. If if does not, the reason may be that the REACTANCE dial setting is too low for a balance. If this is the case, move to a slightly higher setting.

d. Transfer the clip of the connecting lead to the ungrounded lead of the capacitor and rebalance with the RESISTANCE and REACTANCE dials. Suppose the readings are 3.2 ohms and 1870 ohms, respectively. Before corrections, the indicated resistance R_m and reactance X_m are:

$$R_m = 3.2 \text{ ohms}$$

$$X_m = \frac{1870 - 3400}{0.5} = -3060 \text{ ohms}$$

e. Since the frequency is very low, the correction for inductance in the RESISTANCE capacitor is negligible.

f. To correct for the connecting-lead capacitance to ground, determine from Figure 6 the reactance X_a of the short connecting lead at 500 kc. It is -84,000 ohms. Applying equations (1) and (2):

$$A = \left(1 - \frac{-3060}{-84{,}000}\right)^2 + \left(\frac{3.2}{-84{,}000}\right)^2 = 0.927$$

$$R_x = \frac{3.2}{0.927} = 3.45 \text{ ohms}$$

$$X_x = \frac{-3060 - \dfrac{3.2^2}{-84{,}000} - \dfrac{(-3060)^2}{-84{,}000}}{0.927} = \frac{-2948}{0.927}$$

$$= -3180 \text{ ohms}$$

g. From these measurements the capacitance C_x and dissipation factor D_x can be found:

$$C_x = \frac{1}{\omega X_x} = \frac{10^2}{2\pi \cdot 0.5 \cdot 10^6 \cdot 3180} = 100\ \mu\mu f$$

$$D_x = \frac{R_x}{X_x} = \frac{3.45}{3180} = 0.00109$$

5.3 MEASUREMENT OF ANTENNA IMPEDANCE AT 1170 KC.

a. Usually an antenna terminal is so located that the bridge cannot be brought close enough to the antenna terminal to permit use of the short connecting lead. Therefore, screw the long connecting lead into the ungrounded bridge terminal.

b. Using the shortest practicable length of copper strap, ground the bridge case to the metal rack in which the antenna terminal is housed. If the connection to the ground clamp on the case cannot conveniently be made, loosen the panel and slide a piece of copper foil into the crack between the panel and the instrument case. Do not ground to panel screws, as they may not be making contact with the panel because of paint. (If desired, an unpainted 10-32 screw can be substituted for one of the panel screws for a ground connection.)

c. Arrange the connecting lead so that it can be clipped to the antenna terminal or the nearest ground point on the rack with as little change in physical location as possible. The lead should be kept away from metal objects throughout its length.

d. Connect the generator and detector, and check for leakage as outlined in paragraph 3.5. For best results, generator and detector should be fitted with completely shielded coaxial connectors.

e. Since the sign and magnitude of the reactance component are unknown, ground the connecting lead to the rack, set the switch to HIGH, the REACTANCE dial to about 3400 ohms, and establish an initial balance using the INITIAL BALANCE controls.

f. Transfer the connecting-lead clip to the antenna terminal and rebalance with the RESISTANCE and REACTANCE dials. Suppose the readings are 193 ohms and 3250 ohms, respectively. On the first measurement it is usually desirable to check for leakage with the antenna connected. Disconnect the generator coaxial connector and observe the signal magnitude with only the outer shells of the connectors making contact. Any signal that appears is a leakage signal. Repeat this procedure with the detector connector. The effect of leakage detected can be estimated by observation of the amplitude of the leakage signal. After reconnecting the generator or detector, determine the shift from balance of either the RESISTANCE or REACTANCE dial required to produce an unbalance signal equal in amplitude to the leakage signal. The shift in dial reading in ohms is approximately the maximum magnitude of the error. This method does not indicate the distribution of the error between the resistance and reactance measurements.

g. In this measurement the resistance reading is adequately precise, but the reactance reading is not as precise as might be desired because of crowding on the REACTANCE dial scale. For a more precise reactance measurement, initially set the REACTANCE dial nearer to zero, or set the REACTANCE dial to zero and balance the bridge with the antenna connected, using the INITIAL BALANCE controls. If the former method is used, set the REACTANCE dial at a point slightly higher than the difference in REACTANCE readings previously obtained. Since the difference was 150 ohms, set the switch to LOW, REACTANCE to 170, RESISTANCE to zero, clip the connecting lead to ground, and set up an initial balance. Then shift the clip to the antenna terminal and rebalance, using the RESISTANCE and REACTANCE dials. Suppose the readings obtained are 193 ohms and 10 ohms, respectively. Before corrections, the indicated resistance R_m and reactance X_m are:

$$R_m = 193 \text{ ohms}$$

$$X_m = \frac{10 - 170}{1.17} = -137 \text{ ohms}$$

If the latter method is used, leave the RESISTANCE dial set at 193 ohms, and set the REACTANCE dial to zero, with the switch at LOW. Leave the antenna connected and set up an initial balance using the INITIAL BALANCE controls. Transfer the connecting lead clip to ground and rebalance the bridge with the RESISTANCE and REACTANCE dials. The RESISTANCE dial should read zero at balance. Suppose the REACTANCE dial reads 160 ohms. Before corrections, the indicated resistance R_m and reactance X_m are:

$$R_m = 193 \text{ ohms}$$

$$X_m = \frac{0 - 160}{1.17} = -137 \text{ ohms}$$

h. For most accurate results, corrections must be made for effects of the connecting-lead capacitance to ground. From Figure 6, the corresponding reactance (X_a) of the long connecting lead is -16,400 at 1.17 Mc. The corrected impedance can then be obtained from equations (1) and (2).

$$A = \left(1 - \frac{-137}{-16{,}400}\right)^2 + \left(\frac{193}{-16{,}400}\right)^2 = 0.984$$

$$R_x = \frac{193}{0.984} = 196 \text{ ohms}$$

$$X_x = \frac{-137 - \dfrac{193^2}{-16{,}400} - \dfrac{(-137)^2}{-16{,}400}}{0.984} = -136 \text{ ohms}$$

5.4 MEASUREMENT OF A 50-OHM LINE TERMINATED IN ITS CHARACTERISTIC IMPEDANCE AT 50 MC. At very high frequencies, lead corrections are very important. It is also desirable, if possible, to bring up the outer conductor of the coaxial line over the panel and make contact either with the panel directly or with a clamp placed under one of the panel screws. (One of the black panel screws supplied must be replaced with an unpainted 10-32 screw for this application.) (See Figure 9.)

a. Connect the generator and detector, and check for leakage as outlined in paragraph 3.5. At high frequencies, reliable measurements cannot be made unless both the generator and detector are fitted with coaxial connectors.

b. As indicated in paragraph 3.7, either the short clip lead or a short length of No. 20 bus wire can be used for connection to the unknown. Assume that the short clip lead is used for this measurement. Screw the lead into the ungrounded bridge terminal and clip it to ground directly at the end of the coaxial line under test. (See Figure 4b.) The reactance of any ground connection used is therefore included in the initial balance and is not measured as part of the unknown.

c. Since the line is terminated in its characteristic impedance, the measured reactance will be low. Therefore, the REACTANCE dial should initially be set in the lower part of its range, say at 500 ohms, with the switch at LOW. Establish initial balance using the INITIAL BALANCE controls.

d. Transfer the connecting-lead clip to the center conductor of the coaxial line and rebalance with the RESISTANCE and REACTANCE controls. Suppose the readings are 40.5 ohms and 350 ohms, respectively. Before corrections, the indicated resistance R_m and reactance X_m are:

$$R_m = 40.5 \text{ ohms}$$

$$X_m = \frac{350 - 500}{50} = -3.0 \text{ ohms}$$

For a slightly more precise reactance reading, repeat the measurement, with the REACTANCE dial initially set closer to zero.

e. To correct for inductance in the resistance capacitor, determine from Figure 7 the correction for a dial reading of 40.5 ohms at 50 Mc. It is 1.23. The corrected value of resistance then becomes:

$$R_m' = 40.5 \cdot 1.23 = 49.8 \text{ ohms}$$

f. To correct for the capacitance to ground of the connecting lead, determine from Figure 6 the corresponding reactance (X_a) of the short clip lead at 50 Mc. It is -838 ohms. Applying equations (1) and (2) to determine the actual line input impedance, Z_x,

$$A = \left(1 - \frac{-3}{-838}\right)^2 + \left(\frac{49.8}{-838}\right)^2 = 0.996$$

$$R_x = \frac{49.8}{0.996} = 50.0 \text{ ohms}$$

$$X_x = \frac{-3.0 - \dfrac{49.8^2}{-838} - \dfrac{(-3)^2}{-838}}{0.996} = 0 \text{ ohms}$$

g. This example is cited as an extreme case, in which failure to correct for the inductance of the resistance capacitor leads to an error in resistance measurement in the order of 20 percent.

5.5 MEASUREMENT OF BALANCED CIRCUITS. The Type 1606-A R-F Bridge will not measure balanced circuits directly. However, the measurement can be made by an indirect method. In the balanced circuit shown in Figure 8a, the following three impedance measurements are required:

Z_1 = impedance between A and ground, B grounded,

Z_2 = impedance between B and ground, A grounded,

Z_3 = impedance between A and B connected together and ground.

The effective components of the balanced network can be calculated from the following equations:

$$Z_{AB} = \frac{2Z_1}{1 + \dfrac{Z_1}{Z_2} - \dfrac{Z_1}{Z_3}}$$

$$Z_{BC} = \frac{2Z_2}{1 + \dfrac{Z_2}{Z_3} - \dfrac{Z_2}{Z_1}}$$

$$Z_{AC} = \frac{2Z_3}{1 + \dfrac{Z_3}{Z_1} - \dfrac{Z_3}{Z_2}}$$

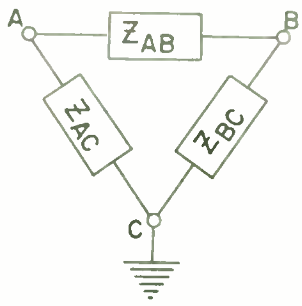


Figure 8a.

If the line is exactly balanced, $Z_{AC} = Z_{BC}$ and $Z_1 = Z_2$.

An auxiliary network to permit direct measurements can be constructed. Details are given in the General Radio Experimenter of September, 1942.

Section 6

CHECKS AND ADJUSTMENTS

6.1 RESISTANCE CALIBRATION. If the RESISTANCE dial calibration changes slightly with time or rough usage, trimmer capacitors C5 and C6, mounted under snap buttons on the panel, can be used to restore calibration. Capacitor C5, under the lower snap button, adjusts the RESISTANCE dial span with the switch at LOW. Capacitor C6, under the upper snap button, adjusts the RESISTANCE dial span with the switch at HIGH. To check calibration, measure the resistance of a good r-f resistor, preferably the carbon-film type, at 1 Mc, with the switch first set at LOW and then at HIGH. The measured resistances at both switch settings should match the d-c value within one percent. If they do not, adjust C5 and C6. Turning these capacitors clockwise decreases the dial reading for a given resistance, and vice versa. Be sure to readjust the initial balance after each adjustment, as the capacitors affect the initial balance as well as the RESISTANCE dial.

6.2 CORRECTION FOR INDUCTANCE IN RESISTANCE CAPACITOR. The change in effective capacitance of the resistance capacitor (refer to paragraph 4.5) is subject to some variation between instruments. Therefore, direct use of the average correction curves of Figures 7 and 8 may lead to error in the resistance measurement. This error is a constant fraction of the correction percentage, and amounts to maximum of ±0.2. That is, if the average correction factor is, say 1.15 (correction percentage = 15%) as determined from Figure 7 or 8, the correction for any individual instrument may be from 1.12 to 1.18. For small corrections, such departures from the average are usually negligible. At the highest frequencies, however, they may be large enough to warrant an individual check on the correction curves.

a. To check the curves of Figure 8, measure a good high-frequency resistor, such as a carbon-composition or carbon-film resistor, whose resistance is known to be 50 ohms, a Type 874-WM 50-ohm Termination, or a Type 874-W100 100-ohm Coaxial Standard, at a frequency of 50 Mc with the switch at LOW. Connect the resistor directly across the bridge terminals or use a very short No. 20 bus wire lead. Suppose the measured resistance and reactance of a 50-ohm resistor are:

$$R_m = 37.7 \text{ ohms}$$

$$X_m = \frac{-600}{50} = -12.0 \text{ ohms}$$

b. The actual resistance "seen" by the bridge is the effective series resistance of the parallel combination of the standard resistor and the connecting-lead capacitance. The effective resistance R_e is:

$$R_e \cong \frac{R_x}{1+\left(\frac{R_x}{X_a}\right)^2} = \frac{50}{1+\left(\frac{50}{-838}\right)^2} = 49.8 \text{ ohms}$$

(This is an approximation because the effective reactance of the resistor is assumed to have a negligible effect. For accurate results, the resistance value should not exceed 2500 f ohms, where f is the frequency in megacycles.)

The correction factor is equal to the ratio:

$$K = \frac{R_e}{R_m} = \frac{49.8}{37.7} = 1.32 \qquad (3)$$

c. The correction factor for this particular instrument can be obtained for any resistance setting from this one measurement through the relation:

$$\frac{R_m'}{R_m} = K = 1 + A(R_m + 560)f^2$$

where f is the frequency in megacycles. R_m' is the effective resistance of the unknown across the bridge terminals (that is, the effective series resistance of the parallel combination of the unknown impedance and the capacitance of the bridge leads and terminal, and R_m is the resistance read from the RESISTANCE dial. Therefore:

$$A = \frac{K - 1}{(R_m + 560)f^2}$$

For the example given:

$$A = 2.13 \cdot 10^{-7}$$

and $$K = 1 + 2.13\,(R_m + 560)f^2 \cdot 10^{-7}$$

A complete set of curves can now be drawn for the particular instrument, either by computation of points from equation (3), or by finding the frequency at which the average correction of Figure 8 agrees with the observed correction and multiplying all frequencies by the ratio of this frequency to the measurement frequency.

Assume that, for a 100-ohm resistor at 50 Mc, K is found to be 1.31. Figure 8 shows a correction factor of 1.31 at about 48 Mc, for a 77-ohm indicated resistance. If all frequencies are multiplied by the ratio 48/50 or 0.96, the curve of Figure 8 may be used directly, or a new set of curves may be drawn with a correct frequency scale.

d. To check the curves of Figure 7, which are valid when the short clip lead is used, the same procedure can be used, except that the clip lead must be used for the connection to the unknown.

$$\frac{R_m}{R_m} = K = 1 + B(R_m + 390)f^2$$

and $$B = \frac{K - 1}{(R_m + 390)f^2}$$

This expression and the K factor differ from those required for the bus wire connection in that they include an effect of the lead inductance not considered in the lead corrections. With the terminals alone or a very short lead, this effect is negligible, but it is significant when the short clip lead is used.

6.3 REACTANCE CALIBRATION. The calibration of the REACTANCE dial is difficult to check accurately, due to the unavailability of capacitance standards that are reliable when mounted on the bridge terminals. However, rough checks can be made as follows:

a. Set the switch to LOW, the REACTANCE dial to its low end, and balance at 1 Mc with the clip lead grounded.

b. Move the REACTANCE dial upscale and try to obtain another null. If the dial is properly oriented with the variable capacitor, no other null will be found.

c. Set the switch to HIGH, the REACTANCE dial to its maximum counterclockwise position (high end of dial), and balance the bridge.

d. Again look for another null. No null should be found, since, if orientation is correct, the variable capacitor will travel slightly less than from its maximum to its minimum capacitance when the dial is rotated from one stop to the other. If two nulls are found, the dial has probably slipped and should be readjusted. To readjust the dial, remove the dial cover, loosen the two set screws locking the dial hub to the shaft, rotate the dial with respect to the shaft, and tighten the set screws.

e. Repeat the search for two nulls and readjust the unit until only one null is found in each case.

For a more accurate check, measure the reactance of several silver-mica capacitors at 1 Mc, and compare the capacitance calculated from the measured reactance ($C = \frac{1}{2\pi fX}$) with the nominal capacitance of the capacitor measured. Be sure to take into account the bridge lead capacitor when making the comparison.

Another method is to measure a capacitor (about 150 μμf) whose capacitance is not accurately known, with the REACTANCE dial set at 3400, and again with the dial at 5000. If the calibration is correct and the dial is properly oriented with respect to the capacitor, the measured reactance will be the same for all three measurements. The most likely cause of a change in the REACTANCE dial calibration is slippage of the hub on the dial or one of the gears caused by loose set screws. After locating and tightening the loose set screws, check and adjust the dial as described above.

Section 7

SERVICE AND MAINTENANCE

7.1 GENERAL. The two-year warranty given with every General Radio instrument attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible.

In case of difficulties that cannot be eliminated by the use of these service instructions, please write or phone our Service Department, giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial and type numbers of the instrument.

Before returning an instrument to General Radio for service, please write to our Service Department or nearest district office (see back cover), requesting a Returned Material Tag. Use of this tag will insure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

7.2 SERVICE.

7.2.1 TROUBLE SHOOTING. The Type 1606-A is a relatively simple instrument, and visual inspection will locate most troubles that may be encountered. The trouble-shooting chart (page 19) lists some troubles that may occur, and corrective measures.

7.2.2 DISASSEMBLY OF RESISTANCE DIAL.

NOTE

> Do not remove the RESISTANCE dial itself unless absolutely necessary, for once it is removed it is difficult to replace it without loss of calibration.

a. Remove cover from panel by removing two screws and lockwashers, below and to the right and left of the shaft opening. This may be done without danger to calibration, as may steps b and c.

b. Remove the knob and plate from the cover by removing two screws and lockwashers from the plate.

c. To separate knob and plate, remove two set screws from the knob.

d. To remove internal ring gear and dial, remove three screws from stop plate.

e. The hub is connected to the capacitor shaft by means of set screws, through an intermediate insulating bushing. The hub is electrically grounded to the panel by three flat springs between the back of the hub and the panel.

7.2.3 RECALIBRATION AND REASSEMBLY OF RESISTANCE DIAL. If the dial has been moved or the calibration lost, recalibrate by measuring the resistance (at any frequency below one megacycle) of various composition resistors whose d-c resistances are accurately known. The measured resistance of each resistor equals its d-c resistance. When replacing the dial, adjust the stops on the gear drive before recalibration, so that they operate slightly before the capacitor reaches the built-in stop at minimum capacitance or the zero end of the dial. To make this adjustment, reorient the gear drive, or, if necessary, loosen the set screws holding the hub to the shaft and rotate the shaft. The set screws are behind the panel at the base of the hub.

To reassemble, simply reverse the disassembly procedure (paragraph 7.2.2). The cover, plate, and knob can be assembled and then mounted as a unit on the dial.

7.2.4 REACTANCE DIAL.

NOTE

> Do not remove the REACTANCE dial unless it is absolutely necessary, for once it is removed it is difficult to replace it without loss of calibration.

The REACTANCE dial has a gear drive similar to that used on the RESISTANCE dial. However, the dial itself cannot be removed without removal of the hub, which is secured to the shaft by set screws. No grounding spring is required.

If the dial is damaged, copy the calibration on a new dial and set the new dial on the shaft as described in paragraph 6.3. The same procedure can be followed if the dial has been removed or if the set screws have slipped. If the calibration is completely lost, roughly calibrate the new dial by measuring the reactance of several silver-mica capacitors (30 to 3000 $\mu\mu$f) at 1 Mc. Their approx-

imate reactances can be computed from their nominal capacitances: $X = \frac{1}{2\pi fC}$. Install and adjust the dial as outlined in paragraph 6.3, and arbitrarily set the zero point near the left-hand end of the range. To determine the point corresponding to the reactance of each capacitor measured, initially set the REACTANCE dial to zero, make the initial balance with the clip lead connected to the capacitor, and make the final balance with the clip lead connected to ground. The final setting in each case equals the reactance of the capacitor and lead measured. Several points can be determined and marked on the dial. The dial is approximately linear in measured capacitance, and a curve can be drawn by means of the measured points and the intermediate points determined.

7.2.5 REMOVAL OF SHIELDS FROM C3 AND C4. There are three nesting shields around capacitors C3 and C4. They are fastened to 1/4-inch aluminum base plates by 6-32 screws at the ends nearest the panel. To remove the outer shield, unsolder the lead to R3 and disconnect the straps between S1 and the shield and between C1 and the shield. Do not apply any more heat than necessary to R3. When replacing the shields, pass the lead to R3 through the grommet hole in the shield by soldering a six-inch length of small-diameter bus wire to the end of the lead, threading the small wire through the grommet, and drawing the lead through as the shield is slipped in place.

7.2.6 REMOVAL OF THE TRANSFORMER. The transformer and the panel connector are permanently fastened together, and the panel connector must be removed before the transformer. The outer shield around the reactance capacitor must be partially removed in order to disconnect the transformer secondary lead. Unsolder the center conductor of the secondary line and remove the nut securing the coaxial fitting to the 1/4-inch aluminum base plate. The transformer itself is mounted to the panel by four screws whose heads appear on the front of the panel.

7.2.7 SPLIT GEARS. If the split gears are removed, they should be reassembled with the upper and lower sections offset when gears are meshed, to provide the spring pressure to eliminate backlash. The springs should be extended two to three full teeth on the large gears and compressed 1-1/2 to two teeth on the small gears.

TROUBLE-SHOOTING CHART

Trouble	Action or Probable Cause
No signal	a. Check generator and receiver connections. b. Check generator and receiver operation by loosely coupling generator to detector or by connecting a voltmeter to bridge end of cable from generator. c. Check frequency band and setting of generator and detector.
Low sensitivity	a. Check cables for short or open circuit. b. Check generator output. c. Check receiver sensitivity and tuning. d. Check bridge circuit for shorts. e. Check transformer by connecting a voltmeter across unknown terminals. Difference between generator voltage and indicated voltage will vary with frequency. At 1 Mc, indicated voltage should be at least one third of generator voltage.
No balance obtainable	a. Clip lead not connected to ground. b. Reactance dial set at point where balance cannot be obtained. (See Figure 5.) c. HIGH-LOW switch at wrong position. d. Unknown impedance beyond direct-reading range of instrument. e. Resistance dial not at zero for initial balance. f. Lead between R4 and ungrounded terminal on panel broken or disconnected. g. One of resistors in bridge burned out. h. Short-circuit in a capacitor.
Resistance dial calibration reads about 20% low	Capacitor C7 open or disconnected.
Balance erratic or noisy	Loose connection or faulty resistor in bridge.
Initial-balance adjustment range shifted	Resistors shifted in value. Check d-c resistances.
Backlash in dials or controls	Check all set screws on shafts.
Bridge balance changes as bridge or various parts of circuit are touched.	Leakage is present. Refer to paragraph 3.5.

Section 8

PARTS LIST

REF. DESIG.	NAME AND DESCRIPTION	LOCATING FUNCTION
C1	CAPACITOR, VARIABLE, AIR DIELECTRIC, plate-meshing type, 30 μμf min, 220 μμf max, special capacity tuning characteristic, 1000 v a-c peak voltage, shaft adjustment, 270 deg cw rotation of plates. Furnished only as complete assembly. General Radio Co. Part No. 916-30.	OHMS RESISTANCE control
C2	CAPACITOR, VARIABLE, AIR DIELECTRIC, plate-meshing type, 55 μμf max, straight line capacity tuning characteristic, 1000 v a-c peak voltage, shaft adjustment, 360 deg continuous rotation, General Radio Co. Part No. 1420-406.	INITIAL BALANCE control
C3	CAPACITOR, VARIABLE, AIR DIELECTRIC, plate-meshing type, 25 μμf min, 220 μμf max, straight line capacity tuning characteristic, 1000 v a-c peak voltage, extension shaft adjustment, 180 deg ccw rotation, General Radio Co. Part No. 1420-405.	OHMS REACTANCE control
C4	CAPACITOR, VARIABLE, AIR DIELECTRIC, plate-meshing type, 25 μμf min, 220 μμf max, straight line capacity tuning characteristic, 1000 v a-c peak voltage, extension shaft adjustment, 360 deg continuous rotation, General Radio Co. Part No. 1420-404.	INITIAL BALANCE control
C5	CAPACITOR, VARIABLE, AIR DIELECTRIC, concentric type, 3 μμf min, 12 μμf max, straight line capacity tuning characteristic, 350 v ac breakdown test voltage, screw-driver adjustment, General Radio Co. Part No. COA-11.	Capacitance to ground equalizer
C6	Same as C5.	Capacitance to ground equalizer
C7	CAPACITOR, FIXED, MICA DIELECTRIC, 15 μμf ±10% tolerance, 500 dcwv, General Radio Co. Part No. COU-24.	
J1	CONNECTOR, RECEPTACLE, banana and binding-post type, not polarized, General Radio Co. Part No. BP-10 (11/16).	Ground binding post
J2	CONNECTOR, COAXIAL, General Radio Co. Part No. 874-307.	GEN. connector
J3	Same as J2.	DET. connector
R1	RESISTOR, FIXED, FILM, 220 ohms ±1% tolerance, not tapped, 1/2 watt power dissipation, JAN RN20X2200F, General Radio Co. Part No. REF-65.	Ratio-arm resistor
R2	RESISTOR, FIXED, FILM, 90 ohms ±1% tolerance, not tapped, 1/2 watt power dissipation, JAN RN20X90ROF, General Radio Co. Part No. REF-65.	Ratio-arm resistor
R3	RESISTOR, FIXED, WIRE WOUND, 330 ohms, ±1% tolerance, 1/4 watt power dissipation, not tapped, General Radio Co. Part No. 1606-304.	Fixed bridge resistor
R4	RESISTOR, FIXED, COMPOSITION, 390 ohms, ±5% tolerance, not tapped, 1/2 watt power dissipation, JAN RC20BF391J, Allen-Bradley Co. Part No. 3915.	Fixed bridge resistor in series with unknown component
S1	SWITCH, KNIFE, General Radio Part No. P1606-37 (cannot be installed as a unit, but is made up of separate elements).	HIGH-LOW switch
T1	TRANSFORMER, RADIO-FREQUENCY, 2 windings single-layer wound; inductance, primary and secondary: 25 μh at 100 kc; turns and wire size, primary and secondary: 2 turns No. 28 AWG enamel copper wire; d-c resistance: primary 0.108 ohm, secondary 0.053 ohm; not tapped, no adjustable tuning, General Radio Co. Part No. 1606-32.	Input transformer

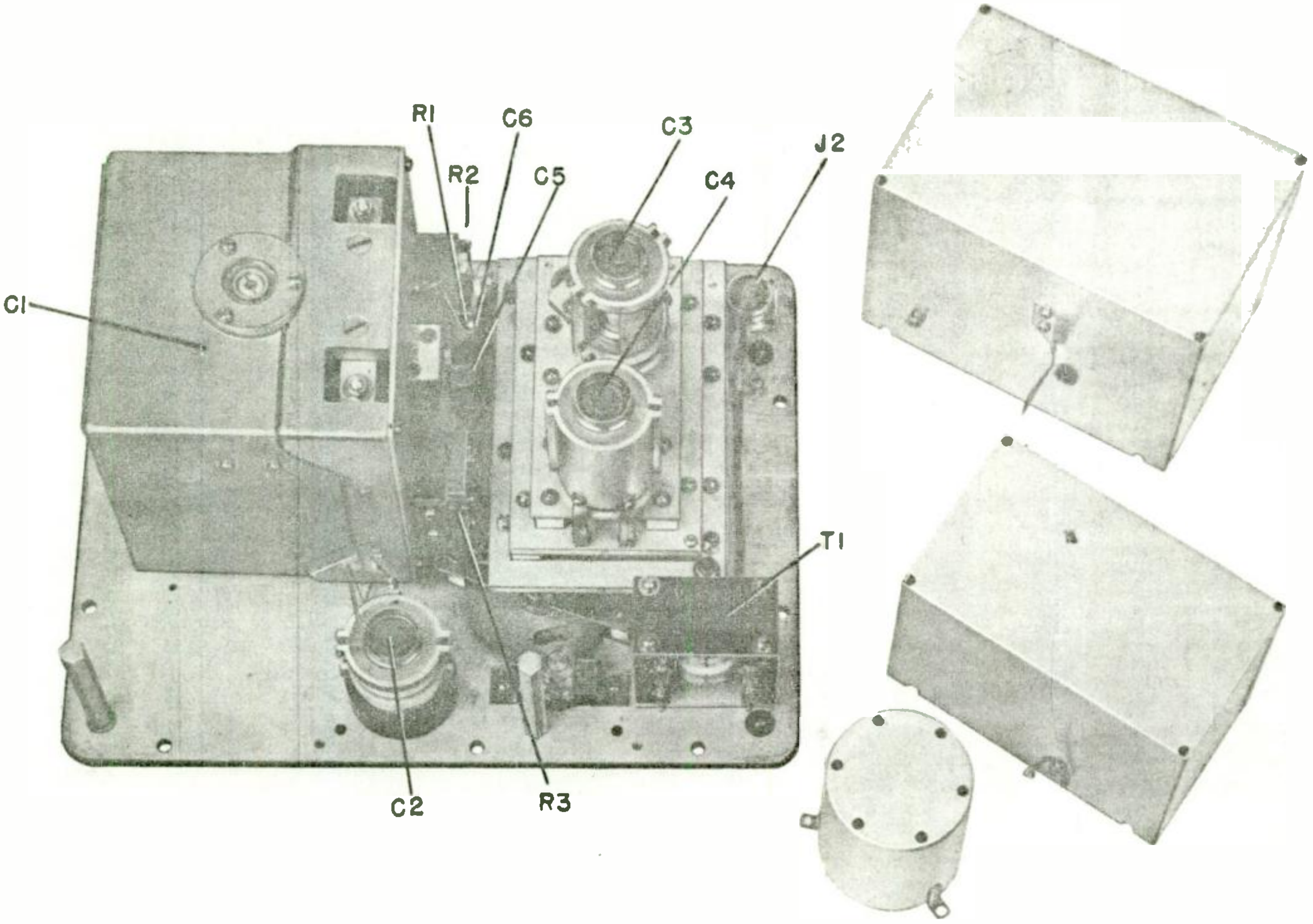
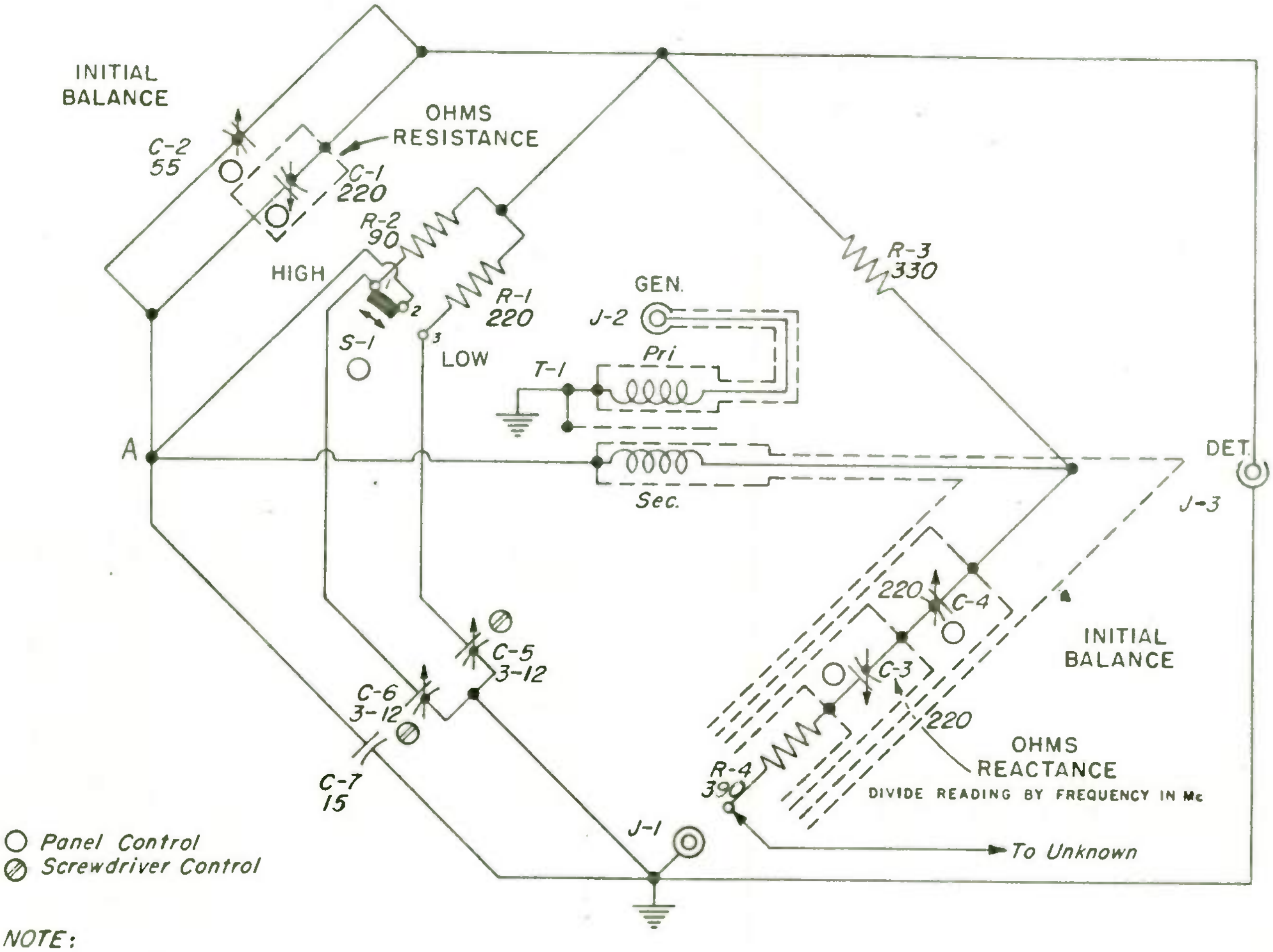


Figure 9. Interior View of Type 1606-A R-F Bridge.



NOTE:

ALL CAPACITANCES ARE IN MICROMICROFARADS

ALL RESISTANCES ARE IN OHMS

Figure 10. Schematic Diagram of Type 1606-A R-F Bridge.

APPENDIX 1

GENERATOR VOLTAGE LIMITS

The maximum generator voltage that can be safely applied to the bridge varies with frequency and with the setting of the HIGH-LOW switch. Figure 11 shows the limits under various conditions. In antenna measurements, the noise and spurious signals picked up by the antenna under test can cause a significant broadening of the null. In instances where the noise pickup is objectionable, an improvement can often be obtained if the generator and detector connections to the bridge are interchanged (generator plugged into DETECTOR connector and detector plugged into GENERATOR connector). If the results are still unsatisfactory, a more selective detector, such as a communications receiver with a crystal filter, should be used or the generator voltage should be increased. As seen in Figure 11, considerably higher voltages can be applied to the bridge when the generator and detector connections are interchanged.

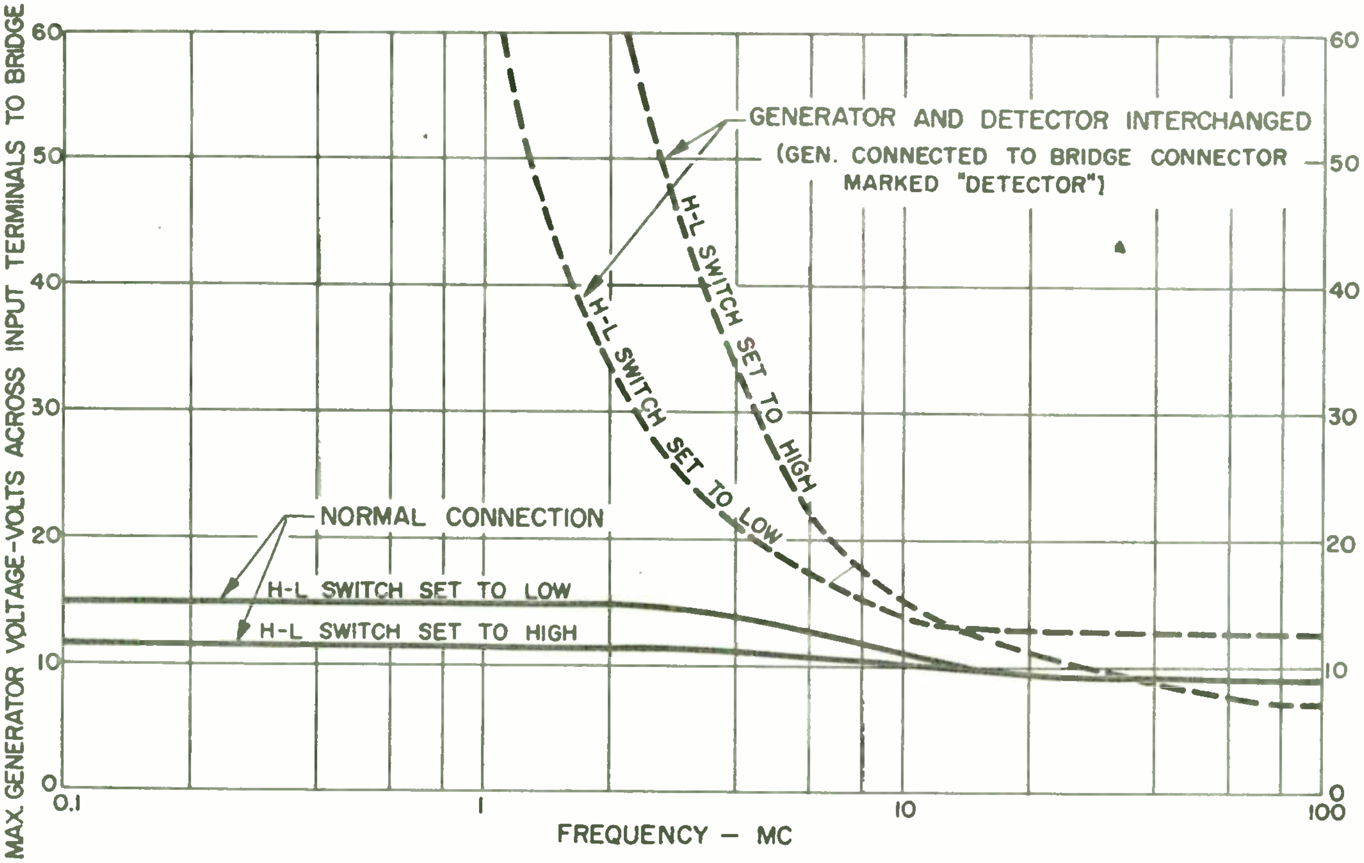


Figure 11. Generator Voltage Limits with Normal and Interchanged Connections.

APPLICATION BULLETIN NO. 1

NEW MEASUREMENTS YOU CAN MAKE WITH THE OIB-1 OPERATING IMPEDANCE BRIDGE

DELTA ELECTRONICS

DELTA ELECTRONICS INC.
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Springfield, Virginia 22151
Telephone: 703/321-9845
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I. DESCRIPTION OF OPERATING IMPEDANCE BRIDGE

The Delta Electronics Model OIB-1 Operating Impedance Bridge is an instrument for impedance measurement and has two main characteristics that make it unique. These characteristics are, (1) its ability to handle a large through power (up to 5 kW with modulation, 10 kW unmodulated); and, (2) its very low insertion effect in the circuit being measured.

It is a characteristic of directional antenna systems that the impedance at each point throughout the antenna system varies according to the tuning of the antenna system. When an ordinary bridge is inserted in such a system, the impedance measured with that bridge is not the actual operating impedance since the insertion of the bridge greatly detunes the system. The OIB-1, on the other hand, can be inserted at any point throughout a directional antenna system. The insertion effect is so low (equal to 9" of 150 ohm line) that the antenna continues to function without significant detuning.

A description will be given below of several of the measurements that can be made with this bridge that cannot be made with an ordinary bridge. There are, of course, many other unique measurements that can be made, as well as measurements that can be made by both types of bridges.

II. FRONT PANEL CONTROLS OF THE OIB-1

The cover is a photograph of the front panel of the operating impedance bridge. The controls on the lower half of the front panel are for the measuring section of the bridge. Those on the upper half are for the detector section. The large dial on the lower right is the resistance dial. The dial on the lower left is the reactance dial. When a null is obtained by adjusting these two dials, the resistance and reactance can be read directly from the engravings on the dials. The lever switch between these two dials is the L-C switch. This switch must be in the L position for inductive loads, and in the C position for capacitive loads. The two lever switches immediately above the R & X dials are adder switches. When an adder switch is thrown in the +100 position, the measured value is the dial reading plus 100 ohms.

The meter in the top center is the null indicating meter. The sensitivity control for this meter is the knob to the right of the meter. The lever switch between this control and the meter is the Forward-Reverse switch. This switch is always in the "Rev." position, except during the SWR measurements described later. The lever switch immediately to the left of the meter is the Tune-Direct switch. When it is in the direct position, the null indicating meter is connected directly to the output of the bridge. When it is in the "Tune" position, a tuneable L network is inserted between the meter circuit and the bridge. This network is tuned by the "Tune" knob. Its use increases the sensitivity of the null measuring circuit.

Provision is made for attaching an external detector to the bridge. A BNC connector for this purpose is mounted on the lower left corner of the panel.

Two high power RF connectors are mounted in recess holes on either side of the bridge case. The connector on the right is the input connector and the one on the left is the output connector. It is to these connectors that the circuit to be measured is attached.

III. MEASURING OPERATING IMPEDANCE

Measurement of the operating impedance at any point in the antenna system can be accomplished as follows: the circuit to be measured is interrupted. A convenient way of doing this is the removal of a meter plug. The clip leads supplied with the bridge are attached to the input and output connectors on the bridge case. The bare leads from both sides are clipped to a good ground point. The insulated lead from the input connector is clipped to the meter jack terminal towards the transmitter. The other insulated lead is clipped to the terminal towards the antenna. Power is then applied to the circuit. The sensitivity control is advanced until an upscale reading is obtained on the null indicating meter. The R & X dials are then manipulated for a null. The sensitivity is then advanced and further adjustments of the dials are made to obtain a deep null. It will be found that the L-C switch must be placed in the proper position in order to obtain a null. It may also be found that one of the dials is rotated to its maximum position before a null is obtained. In this case, the adder switch must be used. When a null is obtained, the operating impedance looking towards the antenna is the dial readings plus the adder switch readings. The reactance value is positive with the L-C switch in the L position, and negative when in the C position. When measurements are made at 1 MHz, the reactance is the value indicated on the X dial (plus the adder switch). For frequencies other than 1 MHz, the reading must be multiplied by the measuring frequency in megahertz to obtain the actual load reactance.

IV. INCREASING SENSITIVITY WITH TUNE CIRCUIT

It will be found that with transmitters of a low power, especially at low frequencies, that it is desirable to have more sensitivity in the null indicating meter. This can be accomplished by throwing the "Tune-Dir." switch to the "Tune" position and rotating the "Tune" knob for maximum meter indication. A substantial increase in sensitivity can be obtained using this circuit.

V. USE OF EXTERNAL DETECTOR

For very low transmitter powers, or when a signal generator is used in place of the transmitter, an external null detector can be used to get the required sensitivity. A well shielded communications receiver can be connected to the external detector jack by a coaxial cable and used as an external detector. Since it is required that the bridge operate with a large through power, the attenuation between the bridge input and the detector circuit has purposely been made large in order to protect the adjustable standards in the bridge. This attenuation places a rigorous requirement on the shielding of an external detector. The adequacy of the external detector shielding can be determined by disconnecting the receiver cable from the external detector jack and putting the body of the plug in contact with the body of the external detector jack. The output indication should be lower than the null value.

VI. MEASURING NEGATIVE IMPEDANCE
(Another Unique Feature of the OIB-1)

Occasionally it will be found that when the dials are manipulated for a null, a balance will be indicated below zero on the R dial. This indicates that that particular part of the antenna system has a negative operating resistance. This characteristic is frequently found in multi-element directional antenna systems. The value of the negative impedance can be measured with the OIB-1. It is accomplished merely by reversing the connection of the clip leads from the bridge. That is, the lead from the IN connector is connected to the circuit towards the antenna. The lead from the OUT connector is connected to the circuit near the transmitter. A bridge null is obtained in the normal manner and readings are taken from the bridge dials in the normal fashion. The actual impedance is the negative of the R & X values read from the bridge.

VII. ADJUSTING MATCHING NETWORKS

After the operating impedance of a single tower is obtained, proper values of network components can be computed by normal equations. When the network is installed, it is convenient to connect the bridge between the input of the network and the transmission line. With the power applied, the network impedance can be measured. The network components can then be trimmed to obtain an exact match for the transmission line. It will, of course, be necessary to re-establish the phase and current ratio each time a change is made in the matching network.

It has been found that if the networks and transmission lines are matched early in the directional antenna tuning procedure, a much better control is obtained with the antenna phasing equipment. This speeds the adjustment of the antenna parameters.

VIII. MEASURING THE COMMON POINT

Adjustments on the phasing equipment of the antenna system to obtain the desired pattern will, unfortunately, change the common point impedance of the system. This changes the input power to the antenna and leaves the engineer in the dark as to the actual radiated power during field measurements. It has been found quite convenient to connect the operating impedance bridge in the common point lead while adjustments are being made. When the phase and current adjustment is made, the engineer can observe the effect on the common point. If the common point resistance is changed substantially, it can be returned by adjusting the appropriate network components without removing the transmitter from operation. The engineer, therefore, has knowledge of the antenna power at all times during the antenna adjustment. Previously, it was often necessary to wait until midnight to determine the actual antenna power by conventional bridge measurements. On occasion it was found that the actual power differed so much from the required power that the field intensity measurements made that day were useless.

The final impedance measurements required by the FCC can be delayed until after the antenna is adjusted. These can, of course, be made in the usual manner with the usual equipment.

IX. LOCATING POWER LOSS

Quite frequently an antenna is adjusted and field intensity measurements reveal that the radiation in the main lobe is somewhat less than predicted. This can be due to several reasons, one of which is abnormal losses in the antenna networks. The Model OIB-1 is a very convenient tool for determining the source of these losses. The operating impedance of each radiator element is measured and the antenna current squared times the operating resistance of each element gives the power delivered to each tower. When these are all added they should very nearly equal the transmitter output power. If this is not the case, measurements can be made at successive points in the antenna system towards the transmitter. The total power at each point can be determined from the operating impedance and the current and the source of the power loss isolated.

X. RENOVATING AN ANTENNA SYSTEM

Sometimes a station will wish to rebuild their antenna phasing gear, transmission lines and networks. The proper design of the new equipment requires a knowledge of the operating impedance of each element of the antenna system. These values can very easily be determined with the Model OIB-1 Operating Impedance Bridge, using the existing networks.

XI. SWR MEASUREMENTS

It is often desirable to measure and record the SWR on the transmission lines of an antenna system. This can be done with the operating impedance bridge by installing the bridge at the input of the transmission line, as described above. The R dial is set to the characteristic impedance of the line, and the X dial is set to zero. The "For. -Rev." switch is thrown to the "Fwd." position and the sensitivity control is advanced until a full scale reading is obtained on the meter. The switch is then returned to the "Rev." position. The SWR on the line can then be read directly from the SWR scale on the meter.

APPLICATION BULLETIN NO. 3

USE OF THE OPERATING IMPEDANCE BRIDGE

DELTA ELECTRONICS

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Talk Given Before The
Georgia Association Of Broadcasters
On Operating Impedance Measurements

(June 16, 1964)

Operating Impedance

It has come as a rude shock to many engineers that the impedance of a circuit, as measured with a bridge, and the actual operating impedance of the circuit are sometimes two very different quantities. In the paper we shall take a second look at this quantity "operating impedance" and investigate the use of a new measuring tool developed for the purpose of measuring this elusive parameter.

In the rawest basic, operating impedance is the vector ratio of a circuit IN ITS NORMAL OPERATING CONDITION.

There are several reasons why the operating impedance of a circuit varies. The circuit varies. The circuit may be non-linear with power or voltage; for example, the incandescent light bulb, or even (unfortunately) most transmitter dummy loads. Or, as in the case of a directional antenna, the circuit may be so complex that it is impossible to introduce a conventional bridge into the circuit without modifying the circuit parameter.

Directional Antennas

A diagram of a simple two-tower directional antenna is shown in Figure 1A. The "T" equivalent circuit for the array is shown in Figure 1B.

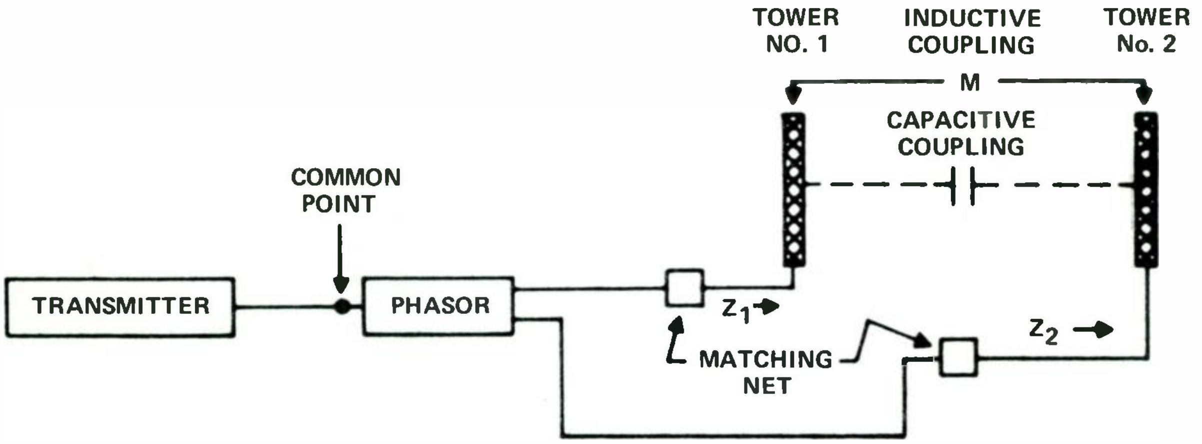
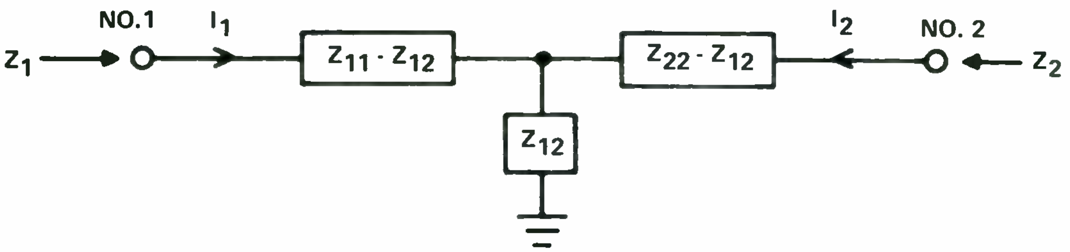


Figure 1A. Two Tower Antenna



Z_1, Z_2 = DRIVE POINT OR INPUT IMPEDANCE OF TOWERS
Z_{11}, Z_{22} = SELF IMPEDANCE OF TOWERS
Z_{12} = MUTUAL IMPEDANCE BETWEEN TOWERS

Figure 1B. Equivalent Circuit Of Antenna System

With the use of the simplified equivalent circuit of Figure 1B, we may see that measuring the input or drive point of a tower in an array is not a simple problem. If Tower No. 2 is disconnected and properly "floated" so that no current (I_2) is allowed to flow, or better yet, completely removed physically, then the input impedance Z_1 is equal to the self impedance (Z_{11}) and is easily measured with a conventional bridge. Note, however, that the requirement for $I_2 = 0$ quite often requires considerable effort to add tuning networks to all the elements in a poly-tower array in order to float all the towers except the one actually being measured.

In the operating configuration (Tower No. 2 connected into the circuit) the input impedance (or drive point impedance) of Tower No. 1 is given by the equation:

$$Z_1 = Z_{11} + Z_{12}\left(\frac{I_2}{I_1}\right)$$

Where, $Z_{12}\left(\frac{I_2}{I_1}\right)$ is the coupled impedance Z_C.

The mutual impedance, Z_{12}, is a function of the physical configuration of the towers and is constant for a given array. The current ratio, I_2/I_1, is a complex vector ratio and is a function of the self and mutual impedance (Z_{11}, Z_{22}, and Z_{21}) and the circuitry in the current paths (which include the matching networks, transmission lines, phasor, etc.).

Since the feed circuit for Tower No. 2 is connected through the phasor to Tower No. 1, the input impedance to Tower No. 1 affects the current in Tower No. 2 (I_2). Thus, placing any impedance in the feed to Tower No. 1 not only changes the current in that tower (I_1), but also changes the current in the other tower (I_2), through the interaction in the phasing equipment. From the equation, it is obvious that a change in the vector ratio of I_2 and I_1, results in a change of the coupled impedance and thus the imput impedance Z_1.

Introducing a conventional bridge into the circuit so radically changes the value of Z_1 that any measurements made this way are useless. As a matter of fact, the only place a conventional bridge may be introduced into a directional array without changing the array parameters is at, or before, the common point.

MEASURING TECHNIQUES

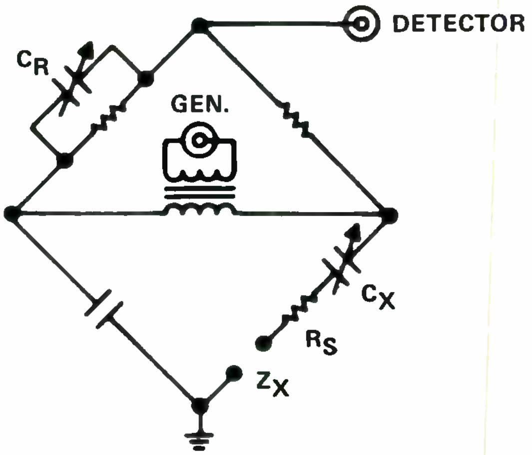


Figure 2. Impedance Bridge (GR Type 1606A)

The Impedance Bridge

The conventional impedance bridge (Figure 2) is a convenient and highly accurate method of measuring regular impedance. It uses a conventional bridge circuit to measure resistance by nulling the detector output with the variable capacitor, C_r, which is calibrated directly in ohms resistance. Reactance is measured by the substitution method: Decreasing the reactance of C_X for a capacitive unknown, or increasing the reactance of C_X for an inductive unknown. The reactance control, C_X, is calibrated directly in ohms reactance normalized to 1 MHz

An excellent feature of this configuration is the use of variable capacitors for measuring both resistance and reactance. The capacitor has many advantages for measuring resistance, including accuracy, linearity, and low contact noise when compared to presently available variable resistors.

A disadvantage of this bridge is that most of the components are above ground and thus are sensitive to stray ground capacities. This requires that these stray capacities be balance out with "initial balance" controls at each frequency before measuring. This is a very tedious and time consuming process when making frequency response measurements.

Although the accuracy of this bridge makes it an excellent choice for common point measurements in a directional array, its configuration makes it unsuitable for drive point measurements. The series and shunt elements between the generator or imput connection and the unknown (Z_x) terminal completely disrupt any circuit into which the bridge is inserted. Naturally, this configuration is also incapable of handling any appreciable power.

Direct Impedance Measurements

Of the two common methods of directly measuring operating impedance, voltage distribution measurements are impractical at low frequencies due to the size of the slotted lines required. The voltage-current measuring technique has been the most practical method of measuring operating impedance, until the introduction of the operating impedance bridge.

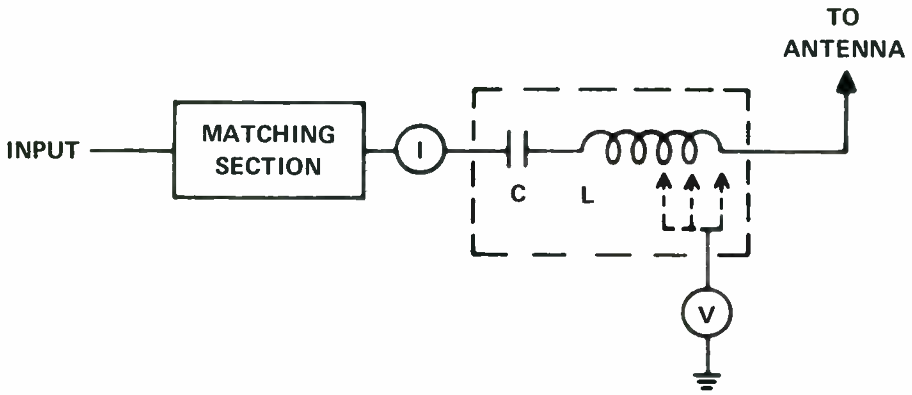


Figure 3. Voltage Current Measurement of Operating Impedance

To measure impedance with this system, the setup shown in Figure 3 is used. The induction (L) and capacitor (C) are set to be series resonance at the operating frequency, so as not to disturb the circuit into which they are inserted. The voltage measured directly across the base of the tower and the current gives the total impedance by: $Z = \frac{V_t}{I}$. However, this gives no phase data.

By measuring the voltage along the inductor (L), a minimum voltage will be found (V_m). (Note: It will be necessary to interchange the inductor and capacitor for an inductive tower in order for the voltage along the inductor to reach this minimum value.) The minimum voltage occurs where the inductor's reactance cancels the antenna's reactance, and this minimum voltage is a function of the antenna's resistance only. The antenna resistance may then be calculated by:

$$R = \frac{V_m}{I}$$

With R and Z known, the reactance, X, and the phase angle may be calculated. While this technique is slow and tedious, it has been used for many years due to the lack of any better procedure.

The Operating Impedance Bridge

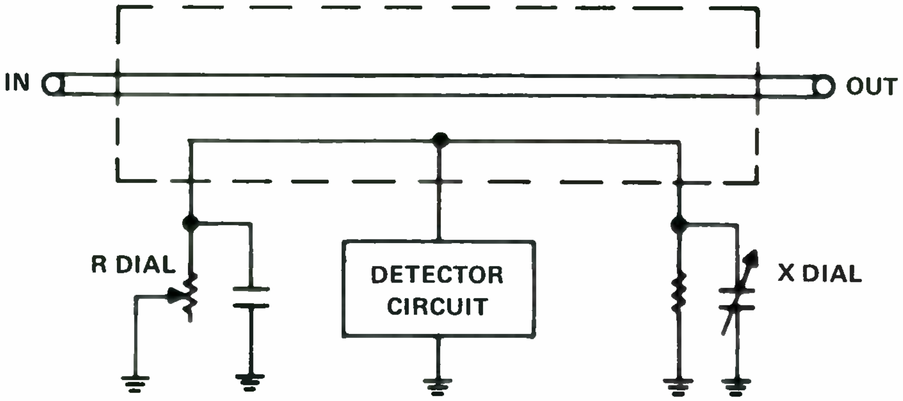


Figure 4. Simplified Schematic Of Operating Impedance Bridge

The Operating Impedance Bridge (OIB)[1] is a new measuring device (patent pending) utilizing distributed capacities and inductive coupling to the center conductor of a short length of coaxial line (Figure 4) to measure the voltage-current vector ratio on the line. The measuring circuit utilizes two controls in a null-balance circuit. The resistance control is calibrated in ohms normalized to 1MHz(The reactance dial is calibrated in $\frac{X}{F_{MHz}}$, and thus is **multiplied** by the frequency in megahertz to determine the actual reactance in ohms. This is opposite from a conventional bridge where the dial reading is divided by the frequency to determine the true reactance.

There are four prime advantages of the operating impedance bridge. First, since the measuring network is very loosely coupled to the circuit being measured, the insertion effect of the bridge is very small (approximately equal to 9" of 150-ohm coax.)[2]. The bridge may be inserted into any point of a directional antenna array with only negligible effect on the array characteristics.

Second, the bridge is designed to operate with considerable thru power (5 kW modulated, 10 kW carrier only with a 3:1 SWR)[2]. Not only does this allow measurements to be made while the system is operating under normal power, but it also allows the use of an internal null detector so that no external detector is required for power measurements.

Third, all of the measuring circuit components are in parallel to ground. This means that any stray capacities are in parallel with the measuring components and may be compensated. The practical result of this is that the circuit maintains balance throughout its operating range, and no "initial balance" controls are required.

Fourth, since the bridge is a "thru" measuring device, the power in the circuit being measured may flow in either direction. By reversing the input and output terminals, the bridge will measure NEGATIVE RESISTANCE directly. The only effect of this operation is the reversal of the "L-C" selector switch.

MEASUREMENTS WITH THE OPERATING IMPEDANCE BRIDGE

Conventional Antenna Measurements

Making accurate measurements on a conventional antenna is often difficult due to the co-channel and adjacent-channel interference received in the detector. This problem is easily overcome for initial tuneups by simply using higher power signal generators with the OIB. Even if transmitter level powers are not permissible due to FCC rules, a higher power signal generator and the use of an external detector with the operating impedance bridge will allow accurate measurements in the presence of the most persistent co-channel signal.

Adjusting Matching Networks

Once the rough setup on a directional array has been accomplished, it is desirable to adjust the tower matching networks to match the transmission line impedance. This is very important for several reasons: First, operating with the transmission line properly terminated provides the phasor with maximum control of the array parameters and minimum interaction of the phasor controls. Second, a high VSWR on the transmission line may easily exceed the line's ratings and cause a breakdown. Third, under mismatch conditions, component ratings in either the phasor or the matching network may be exceeded causing component breakdown.

The matching network may be readily set by measuring the operating impedance of the tower and then calculating the required values of the matching section components to give the impedance match and phase shift. The components may be set to their calculated values by operating the OIB as a conventional bridge with a low level signal and an external detector.

With the components set to their required values, the OIB is connected in series with the input to the matching section and final touchup of the components is made to give the exact match required. It is necessary, of course, to readjust the phases and current ratios at the phasor when a change is made in the matching network. This must be done before the final touchup of the matching network is possible, since the operating impedance of the tower will reflect any changes in the array parameters.

Locating Losses

The ability to measure operating impedance makes the OIB a natural tool for locating system losses. The operating resistance of the input to a network times the square of the current into the network gives the power input. The sum of the powers into the towers of the system should very nearly equal the transmitter output power. If there is a loss, it may be located by determining the power into and out of each circuit of the phasor and matching networks. Losses will often appear as intermittent conditions under power. These are the loose tower bolts, corroded joints, and poor ground joints that measure perfectly with low signal levels and can drive even the strongest of engineers to dispair. Monitoring the suspected circuit with an OIB with power applied, and then shaking and banging on the suspected joints, (insulated tools are advisable, of course) will usually detect even the most perverse of these intermittent conditions.

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[1] "Unique Bridge Measures Antenna Operating Impedance" by Charles S. Wright; "Electronics", Feb. 22, 1963.

[2] Specifications refer to the Delta Electronics, Inc. Model OIB-1, 0.5-5MHz Operating Impedance Bridge.

Monitoring The Common Point

Until the introduction of the Operating Impedance Bridge, one of the greatest difficulties involved in the final adjustment of a directional antenna system was the interaction between all of the phasor controls and the common point impedance.

Without monitoring an excessive number of field points, it is impossible to determine if a field strength change is due to a radiation pattern change, or to a change in the overall radiated power. Even the common method of ratioing field measurements against a non-directional radiation pattern is not useable unless the input impedances to both the phasor common point and the non-directional antenna's drive point are accurately known.

The high levels of co-channel interference that are commonly encountered today quite often preclude the measurements of common point impedances with conventional bridges until after midnight when the interfering stations have gone off the air.

Many consulting engineers have told us that by solving this problem, the OIB is one of their most valued tools. Continually monitoring the common point impedance with an OIB permits easy readjustment of the common point impedance, as required to maintain constant output power, thus eliminating this problem.

There is a special version of the OIB which is the Common Point Bridge (Delta Electronics, Inc., Model CPB-1), made especially for the purpose of permanent installation in a common point. A 50 kW version of this bridge (Model CPB-1A) is also available.

Measuring Techniques With The OIB

The OIB operates in a manner similar to other bridges with a few exceptions. First, the OIB is normally connected in circuits with high power and proper precautions must be exercised. A short circuit at 5 kW is much more spectacular (and expensive) than a shorted signal generator. Also, R.F. burns at this level are much more painful. If the OIB is accidentally ungrounded, very high R.F. voltage may be developed on the case.

Since the OIB is designed to operate with very large thru power, there is high attenuation between the measured circuit and the measuring circuit. This attenuation requires that extreme care be given to R.F. leakage when using an external detector, particularly at signal generator levels. If there is leakage into the receiver from other than the external detector connection on the OIB, the OIB null point will shift and the OIB reading will be incorrect. A well shielded receiver must be used and all interconnections must be made with well shielded coaxial cable.

An easy check for leakage is to disconnect the receiver cable from the OIB external detector jack and hold the body of the cable plug in contact with the body of the OIB jack (i.e., make the ground connection). The output of the receiver should be less than the output when the bridge is nulled.

When measuring tower operating impedances, it is easy to overlook shunting circuits feeding the tower – particularly the lighting circuits. The safest approach is to connect the OIB directly in series with the base current ammeter at the ammeter terminal. It has been found convenient to mount a "J" plug, or a second meter switch with appropriate terminals so that the OIB may be inserted into the circuit at any time without having to remove power from the circuit (again, exercise caution!).

SUMMARY

The Operating Impedance Bridge is capable of making many impedance measurements that heretofore have been very difficult, if not impractical. The OIB is not in competition with the conventional bridge, whose accuracy and usefulness has been proven over the years. Rather, the OIB makes available a new field of measurements that allow greater ease and efficiency of engineering operations.

DELTA ELECTRONICS, INC.

C. Ward Yelverton
Project Engineer

APPLICATION BULLETIN No.5

NEW RF CURRENT SAMPLING COMPONENTS DESIGNED FOR USE WITH AM BROADCAST DIRECTIONAL ARRAYS

Presented to the NAB
Directional Antenna Seminar
in Cleveland, Ohio
October 2, 1974

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The engineers at Delta Electronics, Inc. are in the process of developing a series of components for measuring currents at various points in broadcast antenna systems. Two items have been completed and are now being supplied. Others are under development at the moment and more are being studied. This monolog describes the TCT (Toroidal Current Transformer) family and a companion rectifier circuit.

The first item developed was the Model TCT-1 Current Sampling Transformer. This is a shielded toroidal transformer which, when installed on a current carrying conductor, will deliver an accurate 0.5V rms voltage across a 50 ohm external load for each rms ampere of current flowing in the conductor. The TCT-1 is rated for currents up to 50 amperes and a conductor to ground voltage of 10 KV. Its original purpose was for providing an accurate and stable sampling voltage for antenna monitor systems. To date approximately 200 units of the TCT-1 have been delivered. Reports from the field indicate complete satisfaction with their performance so far. More recently, the Model TCT-2 has been developed and put into production. The characteristics of this unit are identical to the TCT-1 except that it produces 0.25V/ampere and is rated to 75 amperes. Development on a third model, TCT-3, has just been completed. It produces 1V/ampere into an external 50 ohm load.

Physical Description of TCT-1 and TCT-2

A photograph of the TCT-1 giving its overall physical dimensions are shown on the specification sheet. The enclosure box has a 1/2 inch thick aluminum base plate with two blind threaded 1/4-20 mounting holes. The side and top plates are 1/4 inch aluminum and the rear plate is 1/8 inch aluminum. A 1-3/4 inch OD aluminum tube is welded in a hole in the rear plate so that it protrudes 1/8 inch in the front, forming the pass hole for the current carrying conductor. These pieces are seam welded together to form the enclosure box. The front plate is screwed on the box after the internal components are in place. The front plate has a 2 inch diameter hole for clearance of the 1-3/4 inch tube. The internal components are placed in the box along with spacer bars to hold them in place. After wiring connections are made, the cover is screwed in place and the entire inside of the box is potted with type UF-1 non-burning rigid urethane foam encupsulant. All surfaces of the box are then painted with the exception of the bottom mounting surface which is left with a gold iridite finish. A Teflon bobbin is then pressed in the pass hole for conductor insulation. The resulting pass hole will then accept a conductor up to 1-1/4 inches in diameter. The nameplate fastened to the top plate with pressure sensitive adhesive, has a direction arrow indicating the direction of current flow for in-phase sample output on the type N connector.

Electrical Circuit and Its Analysis

Figure 1 is a simplified schematic diagram of the TCT-1 useful for analysis at low frequencies (below 2 MHz).

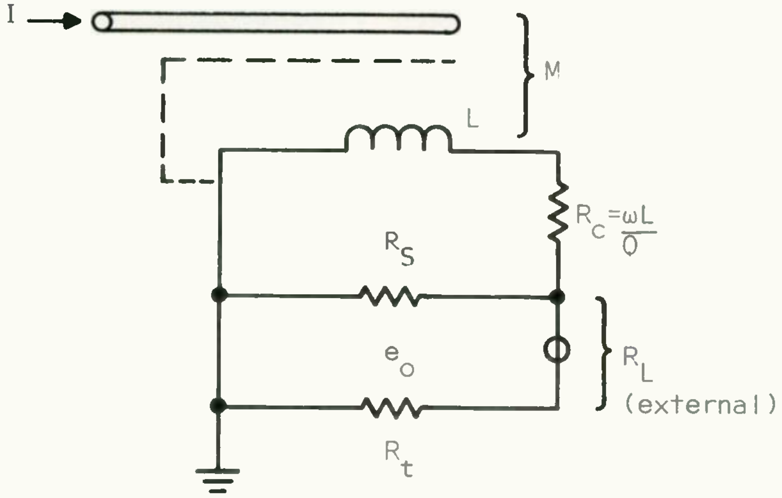


Figure 1 Simplified Schematic Diagram of TCT-1

The total load resistance for the following computations is the parallel combination of the source resistor (R_S) internal to the TCT-1 and the terminating resistance (R_t) of the device receiving the sample (usually an Antenna Monitor).

The voltage induced in the mutually coupled coil (L) is:

$$ei=j\omega MI \tag{1}$$

where: $\omega=2\pi f$, angular frequency is radians/second
M=mutual inductance in Henries
I=current conductor in amperes

the coil current is:

$$i=ei/(R_L+\frac{\omega L}{Q}+j\omega L) = \frac{j\omega MI}{(R_L+\frac{\omega L}{Q})+j\omega L} \tag{2}$$

the output sample voltage is:

$$e_o=R_L i=\frac{j\omega MI\,R_L}{R_L+\frac{\omega L}{Q}+j\omega L} \tag{3}$$

The coil (L) is wound on a torroidal ferrite core and has a self-inducance equal to:

$$L=\mu_r N^2 L_a \quad uH^{1} \tag{4}$$

where: μ_r=relative permability of core
L_a=geometrical inductance of core=$.002H\ \ell n\left[\frac{OD}{ID}\right]$
H=core thickness, CM
OD=core outside diameter
ID=core inside diameter
N=number of coil turns

The mutual inductance (M) between the current carrying conductor passing through such a toroidal coil is given by:

$$M=\mu_r N L_a, \quad \text{uH}^{2} \tag{5}$$

from (4) and (5):

$$M=L/N$$

replacing this value of M in equation (3) above gives:

$$e_o=I\,\frac{j\omega L R_L}{N(RL+\frac{\omega L}{Q}+j\omega L)} = I\,\frac{R_L}{N}\left(\frac{1}{1-j\,\frac{RL+\omega L/Q}{\omega L}}\right)= \frac{IR_L}{N}(K_f) \tag{6}$$

The fraction in paranthesis is the low frequency factor (K_f) which reduces to unity at frequencies where $\omega L >> R_L + \frac{\omega L}{Q}$. Now call:

$$\frac{R_L}{N} = R_o \tag{7}$$

R_o is then a transfer resistance which defines the ratio of sample voltage to sampled current. In the TCT-1, N is 50 turns; the internal source resistor is 50 ohms; and the external load resistance is 50 ohms, making R_L=25 ohms. Thus R_o=.5 ohms or e_o=.5 volts/ampere of current.

When the output of the TCT-1 is not terminated ($R_t=\infty$), RL=RS=50, and R_o=1 ohm or e_o=1 volt/ampere. Thus aside from the frequency factor, it appears as an ideal Thevinen generator of 1 V/A with a source impedance of 50 ohm with an accuracy which is determined only by the number of coil turns and the precision of the source resistor.

One would suspect that there would be error due to the finite coil Q. This, however, is seen to be a modification of the frequency factor adding a small resistance to the RL term in the denominator of this ratio equal to $\frac{\omega L}{Q}$ so that the frequency factor with this included is, from (6):

$$K_f= \frac{1}{1-j\,\frac{R_L+\omega L/Q}{\omega L}} \tag{8}$$

The coil of the TCT-1 is wound on a core whose dimensions are:

H=0.5 inch
OD=3.55 inches
ID=2.05 inches

With N=50 the calculated inductance is 350 μh using the guaranteed minimum permability. Measurements of these coils give a typical inductance of 400 μh with a Q>300. At 500 KHz, ωL=1256 ohms and ωL/Q<4.2 ohms for these measured values.

$$K_f = .99973 \quad \underline{|1.33^\circ}$$

The specification on absolute phase accuracy of the TCT-1 is 2°. This is seen to be satisfied at the lowest specified operating frequency. At higher frequencies, of course, the calculation shown above would yield smaller phase errors.

Of greater interest in most applications, is the tracking accuracy between TCT-1 units. The tolerance on the magnetic properties of the core material is $\pm 20\%$. It is possible, then that there could be a 40% difference in the inductance of the two TCT-1 coils. This could produce a worst case tracking error of $0.4 \times 1.33 = 0.53^\circ$. The phase tracking specification is 0.5° for the TCT-1. Each unit manufactured is tested for this specification and to date none have been found to approach this limit. Typically a 0.2° tracking error is measured over the broadcast band. It is suspected that the core parameters are normally held to much better than the published tolerance. Delta will continue its 100% testing, however, to insure the phase tracking specification.

There is also a high frequency phase error due to the capacity of the winding to the enclosure. Analysis and measurements of these errors show that they have magnitudes comparable to those described above at about 5 MHz and are of little importance at broadcast frequencies.

The core flux density can be computed from:

$$B_{max} = \frac{V_p \times 10^8}{\sqrt{2}\pi f N_p A_e} \tag{9}$$

where: B_{max}=maximum flux density, Gauss (lines/cm^2)

V_p=RMS primary voltage

f=frequency Hz

N_p=number of primary turns

A_e=cross-sectional core area

The primary of the TCT-1 is, of course, the current carrying conductor so that N_p=1. V_p can be determined from the output voltage (e_o) and the turns ratio. Now, within the frequency range of interest from (6) and (7):

$$e_o = R_o I \tag{10}$$

$$V_p = \frac{e_o}{N} = \frac{R_o I}{N} = \frac{R_L I}{N^2} \tag{11}$$

or, $$V_p = \frac{25}{2500} I = .01I \text{ for the TCT-1}$$

for I=50 amps, V_p=.5 volts. A_e is given by the core manufacturer as 2.35 sq. cm. Thus at 500 KHz:

$$B_{max} = \frac{.5 \times 10^8}{4.44(.5 \times {}_{10}{}^{6})2.35} = 9.6 \text{ Gauss}$$

The published saturation flux density for the core material is 3300 Gauss. Thus, error due to magnetic nonlinearity would not be expected. Measurements have confirmed that the TCT-1 is extremely linear.

The flux density is not a limitation on the maximum current that can be measured with the TCT-1. The limitations are the dissipation capability of the source resistor (R_s) and the current carrying capacity of the coil winding. For 50 amps conductor current R_s must dissipate 12.5 watts and the coil wire carries 1 ampere when the TCT-1 is terminated in a 50 ohm load. When unloaded R_s must dissipate 50 watts. The terminating resistor in the TCT-1 is a series combination of two 25 ohm 1% heat-sinks cermet resistors each rated at 30 watts. The heat-sinks of the TCT-1 case is considerably better than that specified by the resistor manufacturer for the rated power, giving an adequate safety factor.

Measurements were made on a TCT-1 to determine its output from electric coupling to the conductor. It was found exceedingly difficult to determine the exact coupling factor because of stray pickup of the receiver used and currents in the conductor due to capacity effects. The measurements clearly indicated, however, that a coupling specification of greater than 100 dB was conservative. That is, the voltage delivered to the load resistance was better than 100 dB below the voltage on the conductor. This is believed to be quite adequate and perhaps orders of magnitude better than conventional sampling loop systems.

The TCT-2 is a modification of the TCT-1 with an R_o of .25 V/A. Its coil is terminated in a 25 ohm resistor and another 25 ohm resistor is placed in series with the coil and the type N connector as shown in the diagram below.

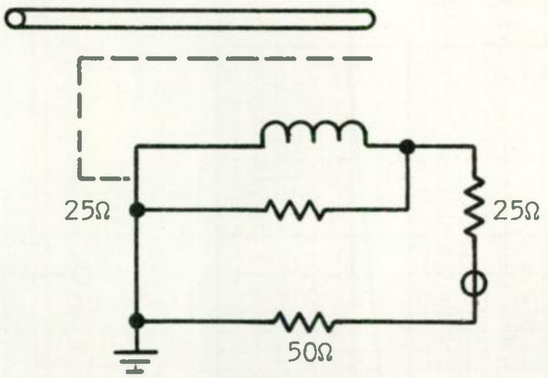


Figure 2 Schematic Diagram of TCT-2

R_L now becomes 18.75 ohmes so the voltage across the shunt 25 ohm resistor is .375 V/A and the voltage appearing across the connector is .25 V/A. Over the frequency independent range, this circuit appears as an ideal Thevinen generator of .5 V/A with a 50 ohm source resistance. Thus, both ends of a 50 ohm transmission line connecting the TCT-2 to the termination are correctly terminated.

When operating terminated and with 75 amperes line current the 25 ohm shunt resistor must disipate 31.6 watts and the series resistor 3.53 watts. Unterminated, these disipations are 56 watts and zero respectively. The shunt resistor is a parallel combination of two 50 ohm 30 watt resistors and the series resistor is a 25 ohm 30 watt resistor. Thus, the TCT-2 can be operated unterminated at full rating.

It is unlikely that a mixture of TCT-1's and TCT-2's would be used in one system because of their different transfer resistances. If they were, however, measurements indicate that a phase tracking error specification of 1° could be easily maintained.

Additional Developments

It is apparent that it is a simple matter to modify TCT series for different transfer resistance and current capabilities. Where the requirements arise, such modification will be made and new models added to the series.

Another fairly obvious development is metering circuit for use with the TCT series so that stable and accurate current magnitude measurements can be made. The circuit could be in the form of a local meter box to serve as a direct replacement for a RF ammeter, a converter for remote analog reading of currents, or with analog to digital converter for remote telemetry. The first requirement of any of these is an accurate, linear, temperature, insensitive AC to DC converter. A modification of such a circuit already in use is Delta's FSM-1 Field Strength Meter has been developed for this purpose. This will be discussed below.

The best economical diode for high level signal rectification is perhaps the silicon junction rectifier family. These diodes have an offset voltage of about 400 milivolts at room temperature. Figure 3 shows the measured voltage drop of a 1N4148 silicon diode at room temperature for forward currents between 0 and 100 μA.

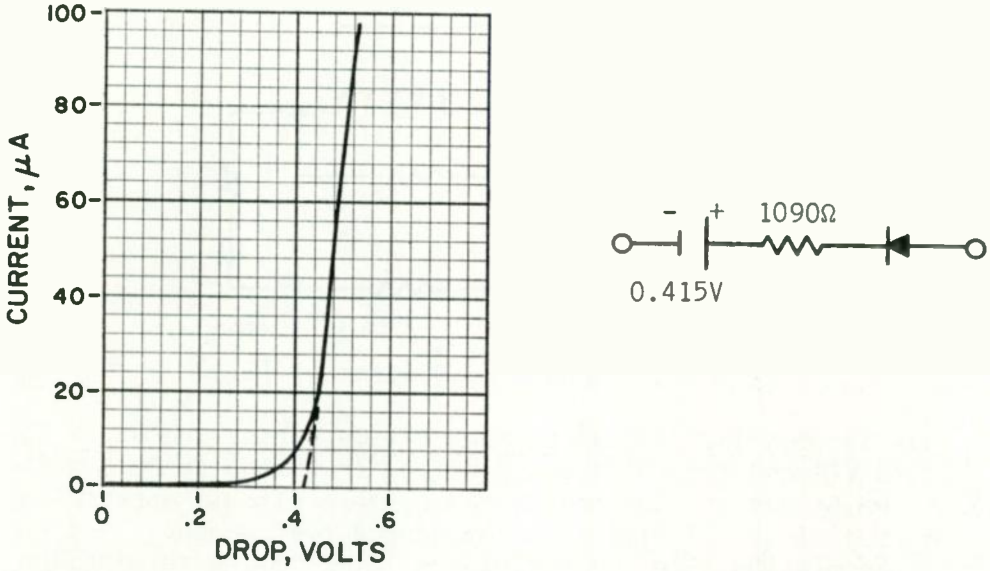


Figure 3 Measured Forward Drop of 1N4148 and Equivalent Circuit

Also shown is an equivalent circuit for the diode accurate over most of this range. It departs from an ideal diode by the equivalent series resistance and offset voltage. The series resistance is no worry when working with high impedance load circuits and can be considered when calculating the load current. The offset voltage, however, can cause serious nonlinearity errors in the AC/DC conversion. The obvious solution is the incorporation of a 415 mv forward bias in the rectifier circuit; and this procedure will give good performance in some applications. The diode offset voltage varies with temperature, unfortunately, and a different offset correction is required for each temperature. One way around this is the use of a temperature regulated heater for the diode to maintain its temperature constant. This method is used in Delta's DAM-1 Antenna Monitor. Another good method is to use a second diode of the same type to regulate the offset correction voltage with temperature. Figure 4 is a simplified circuit of this type as used in the FSM-1. It produces equally good results and requires considerably less power (the FSM-1 is a battery operated device).

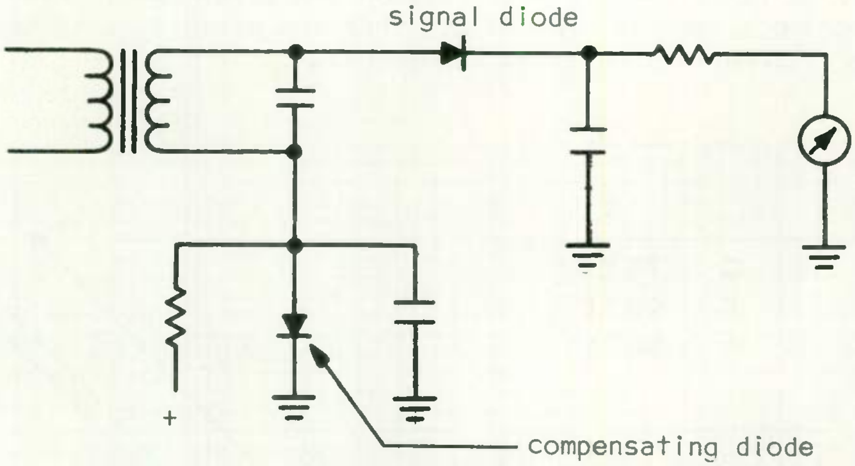


Figure 4 Simplified Diagram of Linear Rectified Circuit Used in FSM-1

When the temperature changes the compensating diode automatically readjusts the compensating offset voltage.

In the FSM-1 the current for the compensating diode is obtained from the emitter circuit of the last IF amplifier so that no additional power is required for this circuit.

It was the target of Delta's development to obtain a linear temperature insensitive circuit without requiring a power supply. It was found possible to obtain the current for the compensating diode directly from the signal power by using the circuit shown in Figure 5.

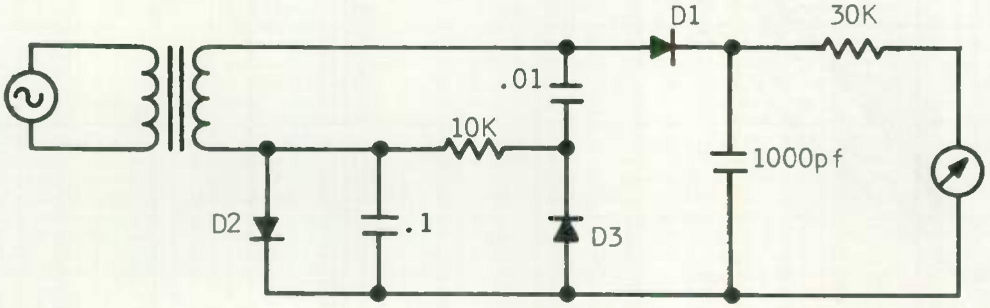
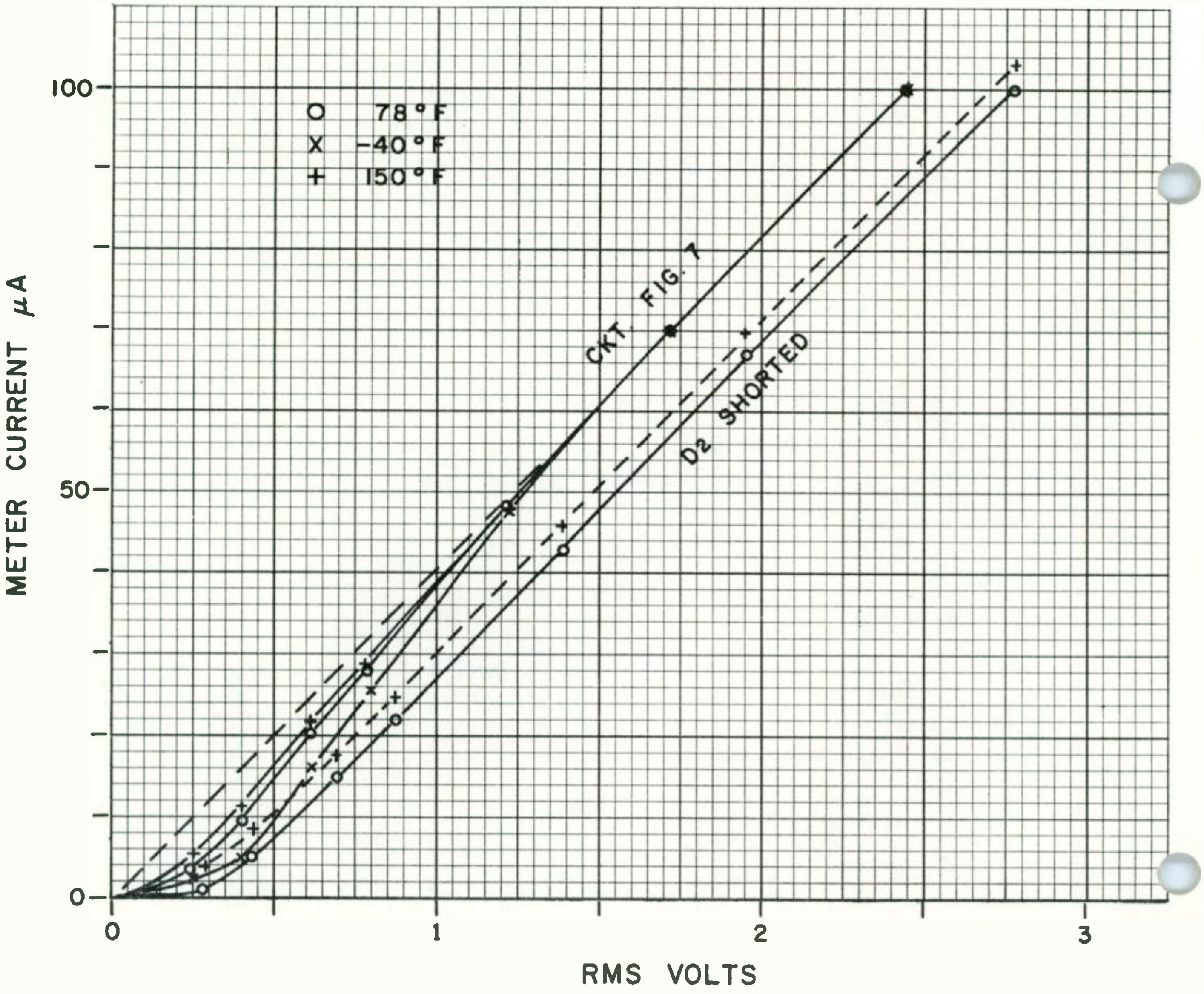


Figure 5 Self Powering Temperature Compensated Rectifier

Diode D1 is the signal rectifier, D2 is the compensating diode and D3 is the source of the compensation current for D2. This circuit, of course, fails at very low signal levels because the offset of D3 prevents it from supplying enough compensation current. It, thus, has a limited dynamic range, which must be considered in any application. Figure 6 shows the low range response of this circuit at various ambient temperatures. These data were measured in the Delta laboratory along with the same circuit without compensation for comparison. This was accomplished by simply shorting D2 for the 78° and 150° measurements. It is seen that above about 1.25 volts the circuit of Figure 5 conforms quite accurately to a linear curve with a zero intercept. With D2 shorted, the response is linear over most of the range but intercepts at an offset voltage that varies with temperature. A good fit with a zero intercept linear curve cannot be obtained under these condition. The lack of a zero intercept can be compensated for easily when the circuit is used with an analog miliameter by suitably marking the scale on the meter face. Even so, the temperature dependence remains a problem. When the circuit is to be used with a A/D converter a zero intercept fit is essential.



Now suppose the circuit of Figure 5 is connected to a TCT-1. The impedance of the circuit is very high compared to the 50 ohm source resistance RS so that 1 V/A will appear at its input. With the meter and multiplier resistors of the circuit selected for 20 volts full scale, the meter will read currents between 1 and 20 amps quite linearly and temperature independent. If a 50 ohm shunt is placed across the input ot the circuit it will become a 40 ampere meter. For small currents, the value of RS in the TCT could be changed or a suitable RF transformer used at the input to the detector circuit.

This approach to current measurement has been found to have an advantage when measuring modulated currents. Its readings will not follow modulation as will a thermoammeter if the filter components are properly selected. This should permit easier and more accurate readings. The readings will, of course, follow carrier shifts.

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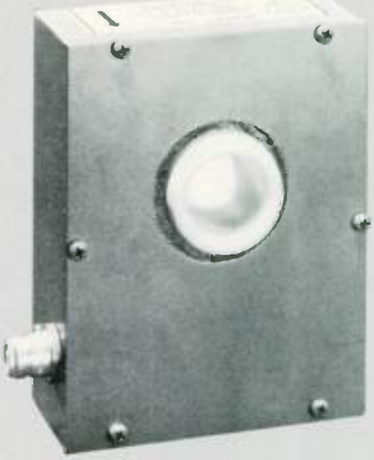
[1] Hoer, Cletus A., Agy, David L., "Broad-Band Resistive-Divider-Type Directional Coupler", IEEE Transactions on Instrumentation and Measurement, Volume IM-19, Number 4, November 1970

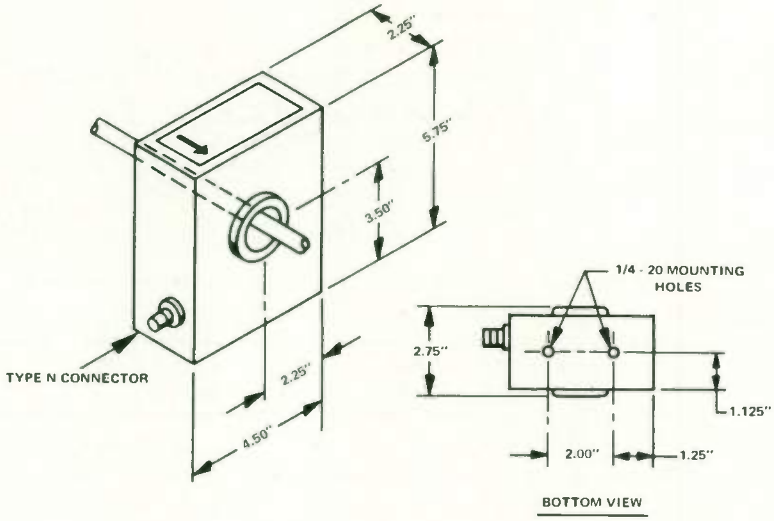
[2] Wanselow, Robert F., "A Self-Compensating Lumped Element Broadband HF Directional Coupler", IEEE, Proceedings of, Volume 55, Number 7, Page 1199, July 1967

Models TCT-1, TCT-2 Toroidal Current Transformers



DESCRIPTION

The TCT-1 and TCT-2 are precision toroidal current transformers designed primarily for obtaining sampling voltages for phase and magnitude measurements on broadcast arrays. The units are housed in rectangular aluminum shield enclosures with a 1-1/4" teflon lined pass hole through which the current carrying conductor is passed. The TCT-1 develops 1 volt RMS output for each ampere of RF current in the conductor with a precision source impedance of 50 ohms. When it is terminated in a 50 ohm load, therefore, 0.5 volts (0.25 volts for TCT-2) per ampere will be developed across the load.



SPECIFICATIONS

FREQUENCY RANGE:
.5 to 2 MHz

SENSITIVITY [1]:
.5V/amp (.25V/amp for TCT-2)

SOURCE IMPEDANCE:
50 ohms

CURRENT RANGE:
0 - 50 amperes (0 - 75 amperes for TCT-2)

ABSOLUTE MAGNITUDE ACCURACY:
±2%

ABSOLUTE PHASE ACCURACY
±2 degrees

MAGNITUDE TRACKING ACCURACY
±1%

PHASE TRACKING ACCURACY
±0.5 degrees

INSULATION
10 kV

ELECTRIC FIELD REJECTION
100 dB

COMPENSATED RECTIFIER CIRCUIT:
TCTR-1 Rectifier available for DC output. See reverse side of this sheet.

[1] When terminated in external 50 ohm load
(Other sensitivities available on special order.)

(over)

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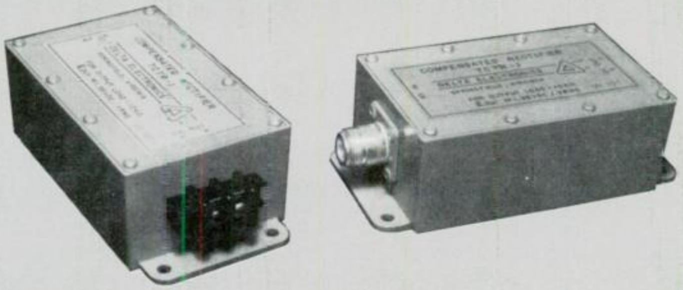
Broadcast Products

Model TCTR-1 Compensated Rectifier Circuit



SPECIFICATIONS

INPUT
Type N Connector
RF from Delta Series TCT Toroidal Current Transformers

OUTPUT
Positive DC voltage

OUTPUT LEVEL
Approximately 1.3 VDC into 10 K DC load for each volt RMS of RF input.

SENSITIVITY
See table below

LINEARITY
5% for input levels of 1.5 to 20 volts RMS

TEMPERATURE RANGE
–20°F to +130°F for linearity and sensitivity within 5%.

(over)

DESCRIPTION

The TCTR-1 is a compensated rectifier circuit intended primarily for use with the Delta Electronics TCT series Toroidal Current Transformers. When used with a TCT it converts the RF sample to a positive DC voltage useful for remote current magnitude measurement.

The TCTR-1 is designed for a 10 kilohm DC load, although it will work well for other load values. When terminated in a 10 kilohm load it will deliver approximately 1.3 to 1.4 volts of DC for each volt RMS of RF input. This factor is linear to better than 5% for input levels of 1.5 to approximately 20 volts RMS.

TCTR-1 SENSITIVITY FACTORS

Current Transformer	RF Input	Approx. DC Output (10 K load)	Useful Current Range
TCT-1 (unterminated)	1V/Amp	1.35V/Amp	2 to 20 Amps
TCT-1 (50 Ω term.)	.5V/Amp	.675V/Amp	4 to 40 Amps
TCT-2 (unterminated)	.5V/Amp	.675V/Amp	4 to 40 Amps
TCT-2 (50 Ω term.)	.25V/Amp	.338V/Amp	8 to 80 Amps

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PRELIMINARY **NEW** **TCT-3**

TOROIDAL CURRENT TRANSFORMER

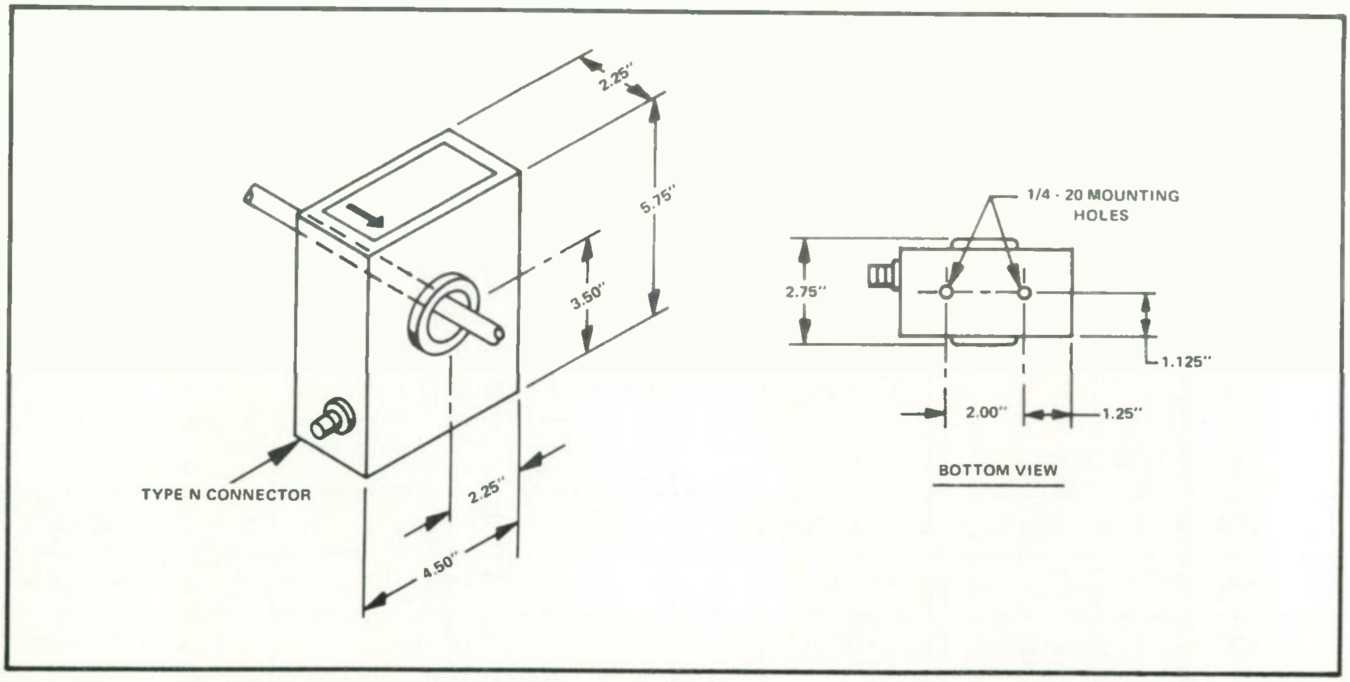
The Delta Electronics TCT-3 is a precision toroidal current transformer designed primarily for obtaining sampling voltage for phase and magnitude measurements on broadcast arrays. This new unit is similar to Delta's TCT-1 and TCT-2, except that the TCT-3 features greater sensitivity and a lower current range.

The TCT-3 Toroidal Current Transformer is housed in a rectangular aluminum shield enclosure with a 1¼ inch teflon lined hole through which the current carrying conductor is passed. The TCT-3 developes 1 volt RMS per amp of RF current when the source impedance is 50 ohms and the load termination is 50 ohms.

TCT-3 SPECIFICATIONS

Frequency Range:	0.5 to 2 MHz.
Sensitivity:	1 volt RMS per amp when terminated in external 50 ohm load. 2 volts RMS per amp unterminated.
Source Impedance:	50 ohms.
Current Range:	0 to 25 amps.

Absolute Magnitude Accuracy:	± 2%
Absolute Phase Accuracy:	± 3 degrees.
Magnitude Tracking Accuracy:	± 1%
Phase Tracking Accuracy	± 1 degree.
Insulation:	10 KV.
Electric Field Rejection:	100 dB.
Connector Type:	Type N female.



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